MONTHLY NOTICES

OF THE

ROYAL ASTRONOMICAL SOCIETY

Vol. 100 No. 4

1940 FEBRUARY 9

ANNUAL GENERAL MEETING

Professor H. C. Plummer, President, in the Chair.

The Minutes of the preceding Annual General Meeting, and the Minutes of the Special General Meeting held 1939 November 10, were read and confirmed.

The election by the Council of the following Fellow was duly confirmed :—

John Cassini Lockerbie, Ford Bank, Wetherby, Yorks.

The following candidate was proposed for election as a Fellow of the Society, the name of the proposer from personal knowledge being appended :—

G. H. Archenhold, D.Phil., Solar Physics Observatory, Cambridge (proposed by Arthur Beer).

The Address on the award of the Gold Medal was delivered by the President (see p. 342), after which the Gold Medal was handed to the First Secretary of the American Embassy, Mr. Rudolf Schoenfeld, for transmission to Dr. Edwin P. Hubble, of the Mount Wilson Observatory, to whom it had been awarded for his outstanding work on the distances, velocities, distribution and nature of the extra-galactic nebulæ.

Visitors were then requested to withdraw and the Society proceeded to the formal business of the Meeting.

The Report of the Auditors was read (see p. 223).

The Treasurer gave some explanation of details of the accounts.

The Annual Report of the Council was partly read.

A vote of thanks to the Auditors of the Treasurer's Accounts for 1939 was proposed and carried unanimously.

It was proposed and carried that the Report of the Council be received and adopted, and that it be printed and circulated in the usual manner, together with the Report of the Auditors and the President's Address.

The President having appointed the Scrutineers, the Society proceeded to the ballot for Officers and Council for the ensuing year. The names of those elected are given on p. 351.

Dr. Steavenson showed some slides bearing on the President's Address.

The thanks of the Society were given to the retiring Vice-Presidents (Professor Greaves and Professor Stratton), Secretary (Professor Plaskett) and other retiring members of Council.

The thanks of the Society were also given to the Scrutineers of the ballot.

The Meeting then adjourned.

REPORT OF THE COUNCIL TO THE HUNDRED AND TWENTIETH ANNUAL GENERAL MEETING OF THE SOCIETY

PROGRESS AND PRESENT STATE OF THE SOCIETY

	Patron	Institutional Members	Honorary Member	Fellows		Associates	Total
				Compounders	Annual Subscribers		
1938 December 31	1	4	1	196	661	48	911
Since elected	...	...	...	+ 1	+41	+2	...
Deceased, 1939	...	...	...	−13	−17	...	...
Deceased before 1939, death not notified	...	...	...	− 2	− 1	...	...
Resigned	...	...	...	...	−14	...	...
Since compounded	...	...	...	+ 3	− 3	...	...
Removed from list	...	...	...	...	− 7	...	...
1939 December 31	1	4	1	185	660	50	901

(Seven Associates are also Fellows, and are therefore counted twice in the above table.)

RECEIVED

	£ s. d.	£ s. d.	£ s. d.
Balances, 1939 January 1 :—			
In hand of Assistant Secretary on Petty Cash Account	5 4 10		
At Bankers', on Current Account	450 14 8		
At Bankers', on Deposit (Cash Balance of Spencer Bequest)	53 19 8		
At Bankers', on "C" Account :—			
Trust Funds £148 17 0			
Proceeds of Sale of Duplicate Books 41 13 0			
	190 10 0		
		700 9 2	
Dividends on Investments (as per schedule)	760 4 3		
Income Tax refunded, 1938 April–1939 April	162 1 5		
Sales of Publications :—			
For 1939 £277 14 3			
Due in 1938 9 8 5			
In advance 22 12 7			
	309 15 3		
Reprints :—			
For 1939 £82 10 4			
Due in 1938 4 6 7			
	86 16 11		
Sales of Photographs :—			
For 1939 £21 11 7			
Due in 1938 2 14 11			
	24 6 6		
Miscellaneous Receipts :—			
London Mathematical Society, Expenses of Meetings, etc. £31 10 0			
Assistant Secretary and Clerk, Pension Premiums 19 5 0			
Use of Telephone 0 9 2			
Postages repaid 3 16 10			
Excess on Subscriptions 0 8 2			
	55 9 2		
Sales of Duplicate Books	31 3 6		
		1429 17 0	
Legacy from the late A. Stanley Williams		150 0 0	
Porter, Pension Contributions		13 0 0	
Franklin-Adams Charts		45 0 0	
Received on account of Subscriptions :—			
530½ Annual Contributions, 1939	1114 1 0		
4 Institutional Membership Fees, 1939	8 8 0		
1 Institutional Membership Fee, 1940, in advance	2 2 0		
7 Annual Contributions, 1940, in advance	14 14 0		
41 Admission Fees, 1939	86 2 0		
37 First Contributions, 1939, at 2 guineas	77 14 0		
4 First Contributions, 1939, at 1 guinea	4 4 0		
Arrears paid off :—			
1 for 1936 £2 2 0			
8½ for 1937, +5s. 18 2 0			
33½ for 1938 70 7 0			
1 Institutional Membership Fee, 1938 2 2 0			
1 Admission Fee, 1938 2 2 0			
1 First Contribution, 1938 1 1 0			
	95 16 0		
		1403 1 0	
Compositions :—			
1 Initial	31 10 0		
3 since compounded	31 10 0		
		63 0 0	
"B" Account :—			
Proceeds of Sale of £200 War Loan 3½% Inscribed Stock (Spencer Bequest)	181 11 6		
Dividends on £500 War Loan 3½% Inscribed Stock (Spencer Bequest)	17 10 0		
Interest on Deposit Account (Spencer Bequest)	0 2 7		
Refund from H.M. Office of Works (unexpended balance of shelving in Spencer Room)	7 11 3		
		206 15 4	
"C" Account :—			
Bequest from the late E. W. Brown	1067 7 7		
Dividends :—			
£1212, 13s. 3d. East Indian Railway 3% Debenture Stock	24 6 9		
£542, 18s. 2d. India 3½% Stock	19 0 0		
£965 Agricultural Mortgage Corporation 4½% Debenture Stock, 1961–91	28 4 7		
£1004 Consolidated Loan 4%	40 3 2		
£540, 10s. 4d. War Loan 3½% Inscribed Stock	18 18 4		
£1067, 7s. 7d. War Loan 3½% Inscribed Stock (half-year's dividend)	20 6 3		
Income Tax refunded, 1938 April–1939 April	21 18 11		
		1240 5 7	
		£5251 8 1	

Examined and found correct.

(Signed) M. G. ADAM
D. S. EVANS

1940 *January* 17

ASTRONOMICAL SOCIETY, FROM 1939 JANUARY 1 TO DECEMBER 31

Account

PAID

	£ s. d.	£ s. d.
Assistant Secretary: Salary	270 0 0	
Clerk: Salary, 10 months £158 6 8		
Clerk: Balance of Salary, 2 months 10 2 10		
	168 9 6	
Assistant Secretary and Clerk, work done for London Mathematical Society in 1939 ...	7 10 0	
Rent of Assistant Secretary's Room at Oxford, 1939 August 26–December 28	36 0 0	
Pension Premiums for Assistant Secretary and Clerk	57 15 0	
Porter and Wife: Wages	151 17 6	
Bonus to Porter	3 0 0	
Health and Unemployment Insurance...	8 10 8	
		703 2 8
Insurance, Taxes and Telephone	... ...	48 3 5
Postage and Packing:—		
Monthly Notices, etc.	166 6 2	
Office Postages	56 4 0	
		222 10 2
Printing, etc.:—		
Monthly Notices (Vol. **99**, Nos. 1–9)	921 15 11	
Geophysical Supplements (Vol. **4**, Nos. 6, 7)	193 11 8	
Occasional Notes (Nos. 3, 4, 5, 6)	90 19 3	
Reprints	149 1 7	
List of Fellows, 1939	42 12 2	
Miscellaneous	52 7 11	
Photo-engraving (*M.N.*, *G.S.*, and *O.N.*)...	121 8 6	
		1571 17 0
Reproduction of Photographs for sale	47 9 6	
Stationery and Office Expenses...	34 4 2	
Hire of Cinema, etc.	6 3 6	
Gold Medal (including engraving)	16 5 0	
A.R.P. Expenditure	108 15 5	
Expenditure from Potter Fund (Library)	6 19 6	
Library Expenditure (General Fund)	2 1 1	
Subscription to International Telegrams Bureau	7 5 9	
Heating and Lighting	118 10 9	
Fittings and Repairs	53 1 2	
House Expenses and Laundry	36 5 3	
Storage of Stanley Williams Telescopes	2 12 6	
Accountant's Fee...	5 5 0	
Authorised Travelling Expenses	13 4 3	
Address to Royal Swedish Academy of Sciences	2 10 0	
Expenses of R.A.S. Meetings and Committees	16 11 6	
Expenses of Geophysical Meetings	3 16 11	
Expenses of London Mathematical Society Meetings	5 7 7	
Bank Charges and Cheque Books	2 15 8	
Miscellaneous Expenditure	26 18 1	
Clerical Assistance	2 2 0	
Purchase of Books from Sales of Duplicate Books Fund	5 17 0	
		524 1 7
		3069 14 10
Expenditure on Franklin-Adams Charts	... ...	0 11 0
Porter's Pension Premium, 1939 August 1–1940 July 31	... ...	26 0 0
Redecoration of Society's Premises	... ...	143 4 6
Expenditure from Spencer Bequest:—		
Purchase of Instruments	85 15 1	
Carpet, etc., for Spencer Room	11 1 0	
		96 16 1
Expenditure on Trust Accounts:—		
George Darwin Lecture Fee	40 0 0	
Turnor and Horrocks Fund (Library)	18 19 3	
Harry Watson Fund (Library)	67 0 7	
Lee and Janson Fund	20 0 0	
Purchase of £1160, 6*s.* 3*d.* War Loan 3½% Inscribed Stock (E. W. Brown Bequest)	1067 7 7	
		1213 7 5
Balances, 1939 December 31:—		
In hand of Assistant Secretary on Petty Cash Account	4 7 9	
At Bankers', on Current Account £298 5 11		
Less Cheque not yet debited 8 0 0		
	290 5 11	
Cheque not yet credited	0 7 0	
At Bankers', on "B" Account (Cash Balance of Spencer Bequest)	163 18 11	
At Bankers', on "C" Account:—		
Trust Funds £172 6 6		
Sales of Duplicate Books Fund 66 19 6		
Goodridge Bequest 3 8 8		
	242 14 8	
		701 14 3
		£5251 8 1

Revenue

	£	s.	d.	£	s.	d.
To General Expenditure (including special A.R.P. expenses, £108, 15s. 5d.) as per Cash Account	3069	14	10			
,, Porter's Pension Premium, 1939 August 1 to December 31, at 10s. a week	11	0	0			
,, Ditto, January 1 to July 31, paid in 1938 and now matured	15	0	0			
,, Reserve for Accounts due but not presented...	125	0	0			
	3220	14	10			
Less Reserve for Accounts due 1938, now written back ...	140	0	0			
				3080	14	10
,, Amount transferred to Composition Fees Reserve Fund, 1939				63	0	0
,, Special Repairs and Maintenance Account: Annual Reserve, 1939 ...				40	0	0
,, 17 Annual Contributions in Arrears (1937–38) written off ...	35	14	0			
,, 18½ Annual Contributions 1939 written off as per contra ...	38	17	0			
				74	11	0
,, Due for Publications 1938, written off				0	5	3
				£3258	11	1

Examined and found correct.

(Signed) M. G. ADAM
D. S. EVANS

1940 *January* 17

Account, 1939

			£	s.	d.	£	s.	d.
By	530½	Annual Contributions, 1939	1114	1	0			
,,	4	Institutional Membership Fees, 1939	8	8	0			
,,	28	Annual Contributions 1939, paid 1938 and now matured	58	16	0			
,,	80	ditto, outstanding...	168	0	0			
,,	18½	Contributions for 1939 due, but unpaid, in respect of Fellows died, resigned, or names removed, and written off per contra...	38	17	0			
						1388	2	0
,,	37	First Contributions at 2 guineas...	77	14	0			
,,	4	ditto at 1 guinea	4	4	0			
						81	18	0
,,	41	Admission Fees	...		...	86	2	0
,,	1	Composition Fee (Initial)	31	10	0			
,,	3	ditto (reduced)	31	10	0			
						63	0	0
,,		6% of Composition Fees Reserve Fund, as per Balance Sheet, transferred to Current Revenue				45	10	4
,,		Sundry Debtors, 1939	30	2	7			
		Less written off, considered irrecoverable in war circumstances	3	0	0			
						27	2	7
,,		Dividends, Sales of Publications and Photographs, and Miscellaneous Receipts, as per Cash Account ...	1429	17	0			
,,		Porter's Pension Contributions, 1939	13	0	0			
			1442	17	0			
		Less Payments due 1938 ... ... £16 9 11						
		Less Advance payments for Publications, 1940 22 12 7						
		Less Income Tax (General Fund) 1938 April–December, refunded in 1939 ... 99 7 5						
			138	9	11			
						1304	7	1
,,		Payments for Publications, 1939, received in 1938 and now matured				53	4	10
,,		Income Tax (General Fund) deducted at source 1939 April–December, not yet refunded				108	10	6
,,		Excess of Expenditure over Income, 1939				100	13	9
						£3258	11	1

Balance Sheet

LIABILITIES

	£	s.	d.	£	s.	d.
1 Institutional Membership Fee 1940, paid 1939	2	2	0			
7 Subscriptions for 1940, paid in 1939	14	14	0			
2 Subscriptions for 1940–41, paid in 1938	4	4	0			
				21	0	0
Sundry Creditors for Accounts due but not presented ...				125	0	0
Cash Balances of Trust Funds—						
E. W. Brown Bequest	20	6	3			
Turnor and Horrocks Fund	5	3	11			
Harry Watson Fund	30	4	10			
Jackson-Gwilt Fund	18	1	0			
Lee and Janson Fund	43	17	9			
George Darwin Lectureship Fund	20	4	9			
A. G. Stillhamer Trust	34	8	0			
	172	6	6			
Cash Balance of Goodridge Bequest	3	8	8			
				175	15	2
Trust Funds and Goodridge Bequest (Capital) as per contra ...				4,582	2	7
Income Tax on Trust Funds, 1939 April–December, not yet refunded				24	14	11
Special Fund (Capital), as per contra				1,460	0	0
Composition Fees Reserve Fund—						
As at 1938 December 31	695	12	9			
Received in 1939	63	0	0			
	758	12	9			
Less 6% transferred to Current Revenue	45	10	4			
				713	2	5
Franklin-Adams Charts—						
Balance of liability from 1938	120	9	1			
Received in 1939 ... ... £45 0 0						
Less due in 1938 ... ... 27 0 0						
	18	0	0			
	138	9	1			
Less expenditure on charts, 1939	0	11	0			
				137	18	1
Advance receipts for publications, 1940				22	12	7
General Fund—						
As at 1938 December 31	19,439	17	8			
Add Dividends and Deposit Interest, Spencer Bequest ...	17	12	7			
	19,457	10	3			
Deduct Loss on sale of War Stock (Spencer Bequest) ...	31	1	8			
	19,426	8	7			
Deduct Expenditure from Spencer Bequest, 1939 ...	96	16	1			
	19,329	12	6			
Add Refund from Office of Works from Spencer Bequest expenditure, 1938	7	11	3			
	19,337	3	9			
Add Stanley Williams Bequest	150	0	0			
	19,487	3	9			
Deduct Excess of Expenditure over Income, 1939	100	13	9			
				19,386	10	0
				£26,648	15	9

Examined and found correct.

(Signed) M. G. ADAM
D. S. EVANS

1940 *January* 17

1939 *December* 31

ASSETS

	£ s. d.	£ s. d.
Sundry Debtors for Subscriptions in Arrears—		
1 for 1937	2 2 0	
20 for 1938	42 0 0	
80 for 1939	168 0 0	
		212 2 0
Sundry Debtors, 1937		1 10 10
Sundry Debtors, 1938		0 16 0
Sundry Debtors, 1939		27 2 7
Investments of General Fund, valued as in 1938 Balance Sheet		19,139 10 11
Investment of Spencer Bequest—		
As at 1938 December 31	531 13 3	
Less Sale of War Stock 3½% £181 11 6		
Less Loss on sale 31 1 8		
	212 13 2	
		319 0 1
Investments of Special Fund, valued at cost		1,460 0 0
Investments of Trust Funds and Goodridge Bequest, valued as in 1938 Balance Sheet	3,514 15 0	
Add Purchase of £1160, 6*s.* 3*d.* War Stock 3½% (E. W. Brown Bequest)	1,067 7 7	
		4,582 2 7
Income Tax 1939 April–December, deducted at source, not yet refunded—		
General Fund...	108 10 6	
Trust Funds	24 14 11	
		133 5 5
Pension Premium for Porter, paid in advance for 1940 Jan. 1–July 31		15 0 0
Sundry Balances—		
In hand of Assistant Secretary on Petty Cash Account ...	4 7 9	
At Bankers', on Current Account £298 5 11		
Less cheque not yet debited 8 0 0		
	290 5 11	
Cheque not yet credited	0 7 0	
At Bankers', on "B" Account (Cash Balance of Spencer Bequest)	163 18 11	
At Bankers', on "C" Account—		
Trust Funds £172 6 6		
Sales of Duplicate Books Fund ... 66 19 6		
Goodridge Bequest 3 8 8		
	242 14 8	
		701 14 3
Repairs Suspense Account—		
As at 1939 December 31	84 8 11	
Excess Expenditure over Office of Works estimate (£131, 2*s.* 4*d.*) for Redecorations	12 2 2	
	96 11 1	
Less Annual Reserve 1939	40 0 0	
		56 11 1
		£26,648 15 9

INVESTMENTS

As at 1939 December 31

General Fund

£1250 Metropolitan Consolidated 3 per cent. Stock, 1941.
£2000 Swansea Corporation 3½ per cent. Stock.
£2287, 6*s.* 9*d.* East Indian Railway 3 per cent. New Debenture Stock.*
£5125 London, Midland and Scottish Railway 4 per cent. Debenture Stock.*
£750 London, Midland and Scottish Railway 4 per cent. Preference Stock.*
£2400 Gas Light and Coke Co. 3 per cent. Consolidated Debenture Stock.*
£2000 Commercial Gas Co. 3 per cent. Debenture Stock.*
£496 Consolidated 4 per cent. Loan, 1967.
£500 Agricultural Mortgage Corporation, Ltd., 4½ per cent. Debenture Stock, 1961–91.*
£1000 Hull Corporation 4½ per cent. Redeemable Stock, 1952–72.
£1000 Central Electricity Board 4½ per cent. Stock, 1957–82.*
£2000 New Zealand 3½ per cent. Loan, 1940.
£700 Birmingham Corporation 3 per cent. Inscribed Stock, 1947.
£1100 War Loan 3½ per cent. Inscribed Stock.
£500 New South Wales 4 per cent. Stock, 1942–62.*
£1156, 1*s.* 5*d.* Metropolitan Water Board 3 per cent. "B" Stock.*
£500 National Defence Loan, 1954–58, 3 per cent. Bonds.*

Grove-Hills Special Fund

£419, 17*s.* 11*d.* Conversion Loan 4½ per cent., 1940–44.
£695, 16*s.* 0*d.* Conversion Loan 3½ per cent., 1961.
£535 Agricultural Mortgage Corporation, Ltd., 4½ per cent. Debenture Stock, 1961–91.*

Trust Funds

£1212, 13*s.* 3*d.* East Indian Railway 3 per cent. New Debenture Stock.*
£542, 18*s.* 2*d.* India 3½ per cent. Stock.
£1004 Consolidated 4 per cent. Loan, 1967.
£965 Agricultural Mortgage Corporation, Ltd., 4½ per cent. Debenture Stock, 1961–91.*
£540, 10*s.* 4*d.* War Loan 3½ per cent. Inscribed Stock.
£1067, 7*s.* 7*d.* War Loan 3½ per cent. Inscribed Stock.

* Taxed at source.

REPORT OF THE AUDITORS FOR THE YEAR 1939

We have examined the Treasurer's accounts of receipts and expenditure, the Revenue Account and the Balance Sheet for the year 1939, and have certified them to be correct. All the investment holdings have been certified by the Bank of England or by the Westminster Bank. There has been no formal revaluation of the investments of the General Fund since 1937, but at our request the Treasurer has estimated their value from the Stock Exchange quotations for 1939 December 31 as £20,878, compared with the figure in the Balance Sheet of £19,139, 10*s.* 11*d.*

The accounts of the Society naturally contain a number of abnormal items arising out of the war. £108, 15*s.* 5*d.* was spent on Air Raid Precautions at Burlington House, including £48 for the provision of a strong room in the basement. The removal of the offices of the Society to the University Observatory, Oxford, where they are now housed by the courtesy of Professor H. H. Plaskett, has necessitated the payment of £36 for the rent of lodgings for the Assistant Secretary in Oxford. The clerk has taken up other work for the duration of the war, and now receives from the Society only the difference between her present salary and her former one. It is to the first large item of exceptional expense that we may attribute the excess of expenditure over income of £100, 13*s.* 9*d.* recorded in the Revenue Account.

The amount of £40 has been transferred to the reserve for repairs and maintenance, and the amount of £63 received for composition fees has been placed to the composition fees reserve fund, which now stands at £713, 2*s.* 5*d.*

A new trust fund has been created during the year as the result of a bequest of $5000 from the late Dr. E. W. Brown. An amount of £1067, 7*s.* 7*d.* was realised and has been invested in 3½ per cent. War Stock. £150 has been received on account from the executors of the late Mr. A. Stanley Williams.

From the Spencer Bequest the sum of £85, 15*s.* 1*d.* has been spent on the purchase of instruments (including a Schmidt camera for the photography of meteors), and £11, 1*s.* has been used for the purchase of furnishings for the Spencer Room. The cash balance of this fund now stands at £163, 18*s.* 11*d.* and the remainder is invested in £300 of 3½ per cent. War Stock.

A list has been laid on the table containing the names of those Fellows who are still in arrear for sums due on 1939 January 1, with the amount due against each Fellow's name.

There has been no opportunity of inspecting the Society's premises at Burlington House owing to their being closed. We have, however, inspected the storage of the large proportion of the Society's early books and manuscripts which are now safely housed in the Crombie basement of the Oxford University Observatory. We are informed that most of those not in Oxford are stored in the new strong room at Burlington House.

We have received from the Assistant Secretary all the information and explanations we required, and we gratefully acknowledge her valuable co-operation in this respect.

(Signed) M. G. Adam
D. S. Evans

1940 *January* 26

GIFTS TO THE GENERAL FUNDS AND PROPERTY OF THE SOCIETY

The John Lee Gift: In 1836 John Lee, Esq., LL.D., gave the Advowson of the living of Hartwell; in 1844 he gave the Advowson of the living of Stone, Bucks. In 1879 these Advowsons were repurchased by his heir, Edward Lee, Esq., for £700.

The Lawson Bequest (1856): Henry Lawson, Esq., bequeathed to the Society the sum of £200, free of legacy duty.

The Carrington Bequest (1876): R. C. Carrington, Esq., F.R.S., bequeathed to the Society £2000 Consols.

The Lambert Bequest (1877): C. J. Lambert, Esq., presented to the Society the sum of £500, free of legacy duty, being part of a sum of money bequeathed by his father, Charles Lambert, Esq., for scientific purposes.

The McClean Bequest (1905): Frank McClean, Esq., LL.D., F.R.S., bequeathed to the Society the sum of £2000, free of legacy duty.

The Farrar Bequest (1906): The Rev. A. S. Farrar, D.D., bequeathed to the Society the sum of £100, free of legacy duty.

The Parsons Gift (1922): The Hon. Sir Charles Parsons, K.C.B., F.R.S., gave to the Society £2500 War Stock 1929–47, in memory of his father, the 3rd Earl of Rosse, who made the 6-foot reflector, and who died 1867 October 31.

The Grove-Hills Bequest (1922): Colonel E. H. Grove-Hills, C.M.G., F.R.S., bequeathed to the Society, free of legacy duty, his collection of early astronomical and mathematical books up to the year 1700, together with a sum of £250 to cover the expenses incurred by the Society in connection with the books.

The Lindemann Bequest (1931): A. F. Lindemann, Esq., bequeathed to the Society the sum of £1000, free of legacy duty.

The Archdeacon Potter Bequest (1933) (*see below*).

The Goodridge Bequest (1936) (*see below*).

The Herbert Spencer Bequest (1936) (*see below*).

The Lindley Bequest (1937): Miss Julia Lindley bequeathed to the Society the sum of £1000, free of legacy duty, which has been received from the Public Trustee in the form of £1156, 1*s.* 5*d.* Metropolitan Water Board 3 per cent. "B" Stock.

THE GROVE-HILLS SPECIAL FUND

In 1922 the Treasurer, Colonel Grove-Hills, collected by his private efforts, with the approval of the Council, a Special Fund to meet the immediate financial difficulties of the Society. The total amount received from all sources (including dividends on the investments representing the fund) has been £1913, 1*s.* 11*d.*, of which £1480, 2*s.* 10*d.* has been invested and is now represented by £535 Agricultural Mortgage 4½ per cent., £419, 17*s.* 11*d.* Conversion Loan 4½ per cent. 1940–44, and £695, 16*s.* Conversion Loan 3½ per cent. 1961.

THE HERBERT SPENCER BEQUEST

Herbert Spencer, Esq., who died in 1903, nominated the Royal Astronomical Society as one of twelve Learned Societies to be eventual beneficiaries of his residuary estate. His estate was wound up in 1936, and the Society's share of the residue amounted to £1241. The conditions of acceptance of the legacy were that the sum received should be spent in certain specified ways by the Governing Body within five years of the date of payment, and might not be used in any way for purposes of endowment. The sum of £732, 11*s.* 9*d.* was temporarily invested in the purchase of £700 War Loan 3½ per cent. (the dividends being added to the value of the bequest), of which £200 stock was sold in 1938 to meet expenditure, and £200 stock was similarly sold in 1939.

Receipts and Expenditure, 1936–1939 *Dec.* 31

	£	*s.*	*d.*		£	*s.*	*d.*
1936. First instalment of Bequest received May 7	500	0	0	1936 Dec. Purchase of £500 War Loan 3½ per cent.	531	13	3
1936. Second instalment received July 20 ...	400	0	0	1936. Expenditure as per 1936 Cash Account ...	276	10	7
1936. Final instalment received Nov. 4 ...	341	0	0	1936 Dec. 31. Cash Balance at Bank, carried forward	432	16	2
	£1241	0	0		£1241	0	0

	£	*s.*	*d.*		£	*s.*	*d.*
1937 Jan. 1. Cash Balance at Bank, brought forward	432	16	2	1937. Purchase of £200 War Loan 3½ per cent.	200	18	6
1937. Dividends, War Loan 3½ per cent. ...	21	0	0	1937. Cash expenditure as per 1937 Cash Account	104	7	6
				1937 Dec. 31. Cash Balance at Bank, carried forward	148	10	2
	£453	16	2		£453	16	2

	£	s.	d.		£	s.	d.
1938 Jan. 1. Cash Balance at Bank, brought forward	148	10	2	1938. Purchase of Instruments	124	7	0
1938. Dividends, War Loan 3½ per cent. ...	24	10	0	1938. Shelving, etc., for Spencer Room ...	193	5	0
1938 Nov. Sale of £200 War Loan 3½ per cent.	198	11	6	1938 Dec. 31. Cash Balance at Bank, carried forward	53	19	8
	£371	11	8		£371	11	8

	£	s.	d.		£	s.	d.
1939 Jan. 1. Cash Balance at Bank, brought forward	53	19	8	1939. Purchase of Instruments	85	15	1
1939. Dividends, War Loan 3½ per cent. ...	17	10	0	1939. Carpet, etc., for Spencer Room ...	11	1	0
1939. Sale of £200 War Loan 3½ per cent. ...	181	11	6	1939 Dec. 31. Cash Balance at Bank, carried forward	163	18	11
1939. Refund from Office of Works on shelving for Spencer Room ...	7	11	3				
1939. Interest on Deposit Account	0	2	7				
	£260	15	0		£260	15	0

	£	s.	d.
1939 Dec. 31.. Balance of Fund still to be expended :—			
£300 War Loan 3½ per cent., valued at cost, as per Balance Sheet	319	0	1
Cash Balance at Bank, on "B" Account ...	163	18	11
	£482	19	0

THE ARCHDEACON POTTER FUND

The late Archdeacon Beresford Potter, who died 1931 May 10, bequeathed to the Society a 3/88th share of his residuary estate. This legacy was received in 1933, and now stands invested in £300 3½ per cent. War Stock, the cash balance of £17, 15*s.* 2*d.* being expended on the library in 1934. The Council resolved to allocate the dividends from this Fund for the purposes of the library.

	£	s.	d.		£	s.	d.
1939 Jan. 1. Balance of Fund	30	4	3	1939. Purchase of Books ...	6	19	6
1939. Dividends, War Stock 3½ per cent.	10	10	0	1939 Dec. 31. Balance of Fund	33	14	9
	£40	14	3		£40	14	3

The Goodridge Bequest (1936) : Captain J. J. L. Goodridge bequeathed to the Society the sum of £50, free of legacy duty. The Bequest has been invested in £49 War Stock 3½ per cent.

	£	s.	d.		£	s.	d.
1939 Jan. 1. Balance of Fund	1	14	4	1939 Dec. 31. Balance of Fund	3	8	8
1939. Dividends, War Stock 3½ per cent.	1	14	4				
	£3	8	8		£3	8	8

TRUST FUNDS

The Lee and Janson Fund : In 1834 John Lee, Esq., LL.D., gave £100, and in 1876 T. C. Janson, Esq., bequeathed £200, the interest to be given to the widow or orphan of a deceased Fellow. These amounts now stand in £334, 10*s.* 9*d.* East Indian Railway 3 per cent. Debenture Stock.

	£	s.	d.		£	s.	d.
1939 Jan. 1. Balance of Fund	54	8	4	1939. Grant from Fund ...	20	0	0
1939. Dividends, East Indian Railway ...	6	14	4	1939 Dec. 31. Balance of Fund	43	17	9
Income Tax, 1938 April–1939 April, refunded ...	2	15	1				
	£63	17	9		£63	17	9

The Turnor Fund and the Horrocks Memorial Fund : In 1853 the Rev. Charles Turnor, M.A., bequeathed a sum of £500, which now stands in £464, 18*s.* East Indian Railway 3 per cent. Debenture Stock. In 1876 the Society received a sum of £38, 15*s.*, the unexpended balance of a fund collected for the purpose of erecting a memorial in Westminster Abbey to Jeremiah Horrocks : to this the Society added the sum of £55, 15*s.*, and the whole now stands in £103, 6*s.* East Indian Railway 3 per cent. Debenture Stock. The interest on these funds is to be used in the purchase of books for the library.

	£	s.	d.		£	s.	d.
1939 Jan. 1. Balance of Fund	8	1	3	1939. Purchase of Books ...	18	19	3
1939. Dividends, East Indian Railway ...	11	8	2	1939 Dec. 31. Balance of Fund	5	3	11
Income Tax, 1938 April–1939 April, refunded ...	4	13	9				
	£24	3	2		£24	3	2

The Harry Watson Memorial Fund : In 1920 Mrs. Watson presented to the Society the sum of £300 as a memorial to her late husband, Lieut.-Col. Harry James Watson, F.R.A.S., the interest on this sum to be used for the purchase of books for the library, such books to be indicated by a special book-plate. This gift now stands invested in £542, 18*s.* 2*d.* India 3½ per cent. Stock. In 1923 Mrs. Watson bequeathed a further sum of £958, 17*s.* to the Society, which now stands invested in £965 Agricultural Mortgage 4½ per cent. Stock. The Council resolved that these two sums should together constitute a Trust Fund, to be designated *The Harry Watson Memorial Fund*, to be used for the purchase and binding of books.

	£	*s.*	*d.*		£	*s.*	*d.*
1939 Jan. 1. Balance of Fund	38	2	0	1939. Purchase of Books ...	19	3	1
1939. Dividends, India 3½ per cent.	19	0	0	Binding	47	17	6
Dividends, Agricultural Mortgage 4½ per cent.	28	4	7	1939 Dec. 31. Balance of Fund	30	4	10
Income Tax, 1938 April–1939 April, refunded ...	11	18	10				
	£97	5	5		£97	5	5

The Hannah Jackson (née Gwilt) Fund : In 1861 Mrs. Hannah Jackson (*née* Gwilt) gave £300 Consols, which now stands in £309, 18*s.* 6*d.* East Indian Railway 3 per cent. Debenture Stock ; the interest to be given in medals or other awards in accordance with the terms of the Trust.

	£	*s.*	*d.*		£	*s.*	*d.*
1939 Jan. 1. Balance of Fund	9	5	6	1939 Dec. 31. Balance of Fund	18	1	0
1939. Dividends, East Indian Railway ...	6	4	3				
Income Tax, 1938 April–1939 April, refunded ...	2	11	3				
	£18	1	0		£18	1	0

The George Darwin Lectureship Fund : In 1926 Sir James Jeans presented to the Society the sum of £1000 for the endowment of an annual lectureship, to be called *The George Darwin Lectureship*, the lecture to be on some subject of interest to astronomers, preference being given, in electing a lecturer, to one normally resident outside the British Isles.

This sum now stands in £1004 Consolidated 4 per cent. Loan. The income is annually applied to the purposes of the Trust in accordance with the terms of the Deed of Gift.

	£	s.	d.		£	s.	d.
1939 Jan. 1. Balance of Fund	20	1	7	1939 June. Lecture Fee	40	0	0
1939. Dividends, Consolidated 4 per cent. Loan	40	3	2	1939 Dec. 31. Balance of Fund	20	4	9
	£60	4	9		£60	4	9

The A. G. Stillhamer Trust (1937): The late A. G. Stillhamer, Esq., F.R.A.S., of Bloomington, Illinois, left all his property outright to Miss Maude S. Capps, of Bloomington; but on account of certain personal memoranda and conversation between Mr. Stillhamer and Miss Capps, the latter resolved to carry out what she believed to have been Mr. Stillhamer's wishes by the payment to the Royal Astronomical Society of the sum of 2500 dollars in cash, the conditions of acceptance being that the principal is to remain intact in the endowment fund of the Society, and the income therefrom to be used annually to pay expenses of scientific research or to purchase definite scientific instruments for use in scientific instruction or research. The Bequest has been invested in £491, 10*s*. War Stock 3½ per cent.

	£	s.	d.		£	s.	d.
1939 Jan. 1. Balance of Fund	17	4	0	1939 Dec. 31. Balance of Fund	34	8	0
1939. Dividends, War Stock 3½ per cent.	17	4	0				
	£34	8	0		£34	8	0

The E. W. Brown Trust (1939): Dr. E. W. Brown, of Yale University, who died in 1938, bequeathed to the Society the sum of 5000 dollars, and desired that the income from the bequest should be used for assistance in the calculation of accurate orbits of the bodies of the solar system, such income as should not be used for this purpose being used for the general purposes of the Society. The bequest was received in 1939 July; it realised £1067, 7*s*. 7*d*. and was invested in £1160, 6*s*. 3*d*. War Stock 3½ per cent.

	£	s.	d.		£	s.	d.
1939 July 7. Bequest ($5000) sold	1067	7	7	1939 Aug. 2. Purchase of £1160, 6*s*. 3*d*. War Stock 3½ per cent. ...	1067	7	7
1939 Dec. 1. Dividends on £1160, 6*s*. 3*d*. War Stock 3½ per cent. ...	20	6	3	1939 Dec. 31. Balance of Fund	20	6	3
	£1087	13	10		£1087	13	10

CELESTIAL PHOTOGRAPHS

The following have been added to the list of Celestial Photographs reproduced by the Society as slides and prints for sale to Fellows :—

R.A.S. Serial No.	Ref. No.	
520	M 53.	Infra-red Spectrum of Sun and Venus. Mt. Wilson. Showing carbon dioxide bands.
521	M 56.	Spectrum of Saturn and Jupiter. Mt. Wilson. Near infra-red. Showing ammonia bands.
522	M 54.	Spectrum of Mars. Slipher, Lowell Obs. Showing water vapour band.
523	M 51.	Spectra of Moon and Major Planets. V. M. Slipher, Lowell Obs. 1907.
524	M 58.	Spectrum of Saturn and rings. Lowell Obs. Showing methane band in spectrum of ball.
525	K 4·1.	Cluster N.G.C. 6440. Baade, Mt. Wilson. Blue light, exp. 50 m. Red light, exp. 75 m.
526	K 4·2.	Cluster N.G.C. 6553. Baade, Mt. Wilson. Blue light, exp. 50 m. Red light, exp. 75 m.
527	L 20·1.	Sagittarius Cloud. Baade, Mt. Wilson. Blue light, exp. 60 m. Red light, exp. 90 m.

PUBLICATIONS OF THE SOCIETY

During the past year the Society has published *Monthly Notices*, vol. 99 ; *Geophysical Supplements*, vol. 4, Nos. 6 and 7 ; *Occasional Notes*, Nos. 3, 4, 5 and 6 ; and List of Fellows, 1939.

INSTRUMENTS

During the year the late A. Stanley Williams, Esq., bequeathed to the Society his $6\frac{1}{2}$-inch reflecting telescope, mounted in a metal tube on a fixed latitude iron equatorial stand (with fixed driving circle and moving worm). He also bequeathed a $9\frac{1}{4}$-inch mirror, mounted in a wooden tube which is designed to fit the stand for the $6\frac{1}{2}$-inch telescope, and several smaller instruments and accessories.

OBITUARY

The Council regret that they have to record the loss by death of the following Fellows during the past year :—

Clement Osborn Bartrum
John Morton Billing
*Percy Francis Ward Blake
Charles Lewis Brook
J. B. Ayscough Clarke
Andrew Claude de la Cherois Crommelin
Henry Percy Douglas
John William Durrad
Frank Watson Dyson
William Moses Feldman
David Ross Fotheringham
Park Goff
Herbert Hedley
†Wendell Phillips Hoge
Henry Park Hollis
*James Thomas Jackson
James Chisholm Jenkinson
Frederick George Jones
Arthur Edwin Kennelly
Arthur Everard Levin
Arthur William Long
Charles Nielsen
William O'Leary
William Lipscombe Orpwood
Montague Austin Phillips
Cyril Potter
Herbert George Robins
Ralph Allen Sampson
Martin Charles Sharp
Henry Hayden Waters
‡Henry Charles Watson
Jacob Werner

CLEMENT OSBORN BARTRUM was born on 1867 October 6 at Bradford, in Yorkshire, but came with his parents to London when only nine years old. He was educated at the Mercers School, where he won a scholarship, afterwards, when sixteen, entering a firm of worsted manufacturers,

* Died 1938 ; death not reported till 1939.
† Death reported too late for a Notice.
‡ Died *circa* 1935 ; death not reported till 1939.

and later becoming a partner in a similar business from which he retired in 1929.

His scientific education was undertaken entirely on his own initiative, as he devoted his evenings to an intensive study of many branches at the Birkbeck College, taking his B.Sc. degree.

He was a great reader, and was fortunate in having a very versatile mind, so that his general all-round knowledge of scientific and other matters was somewhat unusual. Besides astronomy he had great interest in geophysics and, particularly, in the mechanism and design of precision clocks. In 1913 he designed and constructed a clock which comprised the first successful mechanism for the control of a slave clock by a master pendulum. There is no space to describe this clock here, but a full account of it is given in a paper which Bartrum read before the Physical Society in 1916 and in which he discusses the problem from a mathematical as well as from a mechanical viewpoint. It may, however, be mentioned that among the many clever and unique devices included in the mechanism of this clock was one which secured synchronisation in "rate" as well as in "phase" between the pendulums without "hunting," which, so far as I am able to ascertain, has never yet been accomplished by any other device.

Among other of Bartrum's inventions were a barometric compensator for clock pendulums and an open scale barometer in which, by means of a special liquid, resting on the mercury surface and contained in a capillary tube, readings at the critical part of the scale are magnified some eight times.

Bartrum was a prominent member of the British Astronomical Association, which he joined in 1912. He presented a number of papers to this Association, was its Secretary from 1930 until his death, and also Curator of its instruments. He was a Fellow of the Physical Society since 1898, and was one of the founders of the Hampstead Scientific Society, with which he was closely associated for thirty-six years as Secretary and Treasurer.

He was a regular attendant at both the astronomical and geophysical meetings, being well known to Fellows usually attending these meetings. He was Auditor for the Society in 1927 and again in 1933. He represented the British Astronomical Association on the Geophysical Committee of the Society at the time of his death.

Bartrum was one of the kindliest and most unassuming of men. He was very fond of music and delighted in country walks. He lived at Hampstead from his first arrival in London until his death, after a short illness, on 1939 April 28, in his seventy-second year. In 1906 he married Kate Isabel Shattock, who survives him with a son and two daughters.

He was elected a Fellow of the Society on 1920 February 13.

F. J. SELLERS

JOHN MORTON BILLING, who died in Singapore on 1939 January 9, was a civil engineer by profession. Born in Blackpool on 1903 February 1, he went out to the Straits Settlements after completing his engineering training in this country. There he was employed by the Malayan Civil

Engineering Service in the Public Works Department, in which he was outstanding for his ability. His work has been publicly recognised by the posthumous award of the Premium for 1937–38 for the most meritorious paper of the year, by the Malayan Association of the Institution of Civil Engineers. In making this award the Association referred to the high standard of Billing's work and the great loss which the profession had sustained by the death of one who had reached such a high standing at so early an age.

From his youth up Billing was interested in astronomy, and although he never subordinated his engineering work to this interest, he nevertheless found time to contribute a series of astronomical articles to the *Straits Times* of Singapore.

His tragic death will be felt not only by his scientific colleagues, but by all who knew him. He was unmarried.

He was elected a Fellow of the Society on 1930 January 10.

CHARLES LEWIS BROOK, of Harewood Lodge, Meltham, Huddersfield, died there on 1939 May 9, aged eighty-three. He was elected a Fellow of the Society on 1899 January 13, his sponsor being the Rev. T. H. E. C. Espin. In the years following his election he was much interested in observations of phenomena in the debatable borderland between astronomy and meteorology. Between 1901 and 1910 he wrote frequently in the *B.A.A. Journal* on such subjects as the cause of dark or copper-coloured lunar eclipses, the path of fireballs, the Green Flash, the Zodiacal Light, and the extent and positions of the Gegenschein, which he seems always to refer to the ecliptic. In the Solar Eclipse of 1900, which he and his sister, Mrs. Arthur Brook, observed at Algiers, they devoted their attention to the shadow bands, which they considered to be purely meteorological; they also looked for the approaching and receding shadow. In 1910 he took over the Directorship of the Variable Star Section, and, from this time on, he devoted his energy to the correlation of observations of the other members of the Section in a series of *Memoirs* of incalculable value. During the twelve years in which he continued to hold the Directorship he was responsible for a large number of Interim Reports, necessitating the co-ordination of a great number of observations; his careful work both before and during this period, as well as his generosity in himself sharing, to a considerable extent, in the cost of the publication of the *Memoirs*, constitutes a lasting and valuable contribution to the B.A.A., and to astronomy in general. Like Colonel Markwick, his predecessor as Director of the Section, he believed in the co-operation of observers, and it is due to his organisation of this aspect of the duties of a Director that so much valuable data were yielded by the observations.

From 1915 to 1929 he published in the *B.A.A. Journal* papers on three irregular variables, long-period variables, and SS Cygni; he continued his observations of the latter star until 1924, and was responsible for correlating observations until much later. As far as can be gathered he published no papers in *Monthly Notices*, but to him was entrusted in 1908 the

editing of Pogson's Observations of 31 Variable Stars, which appeared in *Memoirs*, 58.

Brook was born in Meltham and, apart from the years which he spent at Uppingham and Oxford, he lived there all his life.

A. S. D. MAUNDER

ANDREW CLAUDE DE LA CHEROIS CROMMELIN was born 1865 February 6 and died 1939 September 20. He was the third son of the late Nicholas de la Cherois Crommelin, a descendant of Louis Crommelin, Huguenot founder of the linen trade in Ulster.

He was educated at Marlborough College, passing thence to Trinity College, Cambridge, becoming a Scholar in 1884 and graduating as 27th Wrangler in 1886. After leaving Cambridge he was for a time on the staff of Lancing College, and then made a trial of electricity as an occupation, but neither held him. Even in childhood Crommelin was a keen observer of the stars; at Cambridge he already had a reputation for a knowledge of astronomy, and was elected into the Royal Astronomical Society before leaving the University, so that it was fortunate that, in 1891, the appointment of an additional Assistant at the Royal Observatory, Greenwich, was authorised by the Admiralty; Crommelin, sitting in competition with the late E. W. Brown, secured the appointment.

Joining the staff of the Royal Observatory on 1891 May 11, Crommelin took his place among its members for the regular routine observations with the transit circle, the altazimuth and the Sheepshanks equatorial. He was made responsible for the altazimuth (the instrument designed by Airy for observing the Moon) and the Sheepshanks equatorial, and for the reduction of observations of the Moon, occultations of stars by the Moon and of observations of comets. When the Airy altazimuth was replaced by the larger new altazimuth or Universal Transit Circle this also was placed in his charge.

At this time observations of comets were made with the old-fashioned cross-bar micrometer on the Sheepshanks equatorial and, although Crommelin introduced such improvements as were possible, the results were hardly encouraging to a keen observer. Nevertheless the reduction of these observations took him into a field of activity suitable to his talents. The orbits of comets and minor planets became his chief interest and remained so to the end. He took comets and cometary orbits into his special care, and in an early number of the *Journal of the British Astronomical Association* we find a paper "On the Determination of the Orbit of a Comet or Minor Planet from three Observations made at an Interval of a few Days."

Crommelin was for many years Director of the Comet Section of the British Astronomical Association, and in response to a desire expressed at the meeting of the International Astronomical Union in Rome in 1922 he undertook to supervise the work of producing a sequel to Galle's Cometenbahnen. This he did, with the aid of the Computing Section of the Comet Section of the B.A.A., and the Comet Catalogue was published in 1925 and, with subsequent continuations, kept up to date. In this connection mention should be made of a large paper in the *Memoirs* of the R.A.S. giving "Tables

for Facilitating the Computation of Perturbations of Periodic Comets by the Planets."

In a paper read at the R.A.S. in December 1906 Crommelin pointed out that the predictions of the date of the coming perihelion passage of Halley's Comet, as given by Angstrom and Pontécoulant, differed by nearly three years and suggested that a revision should be made. He approached P. H. Cowell, who agreed to collaborate, with the result that the method of calculating the perturbations of long-period comets was simplified and the necessary formulæ put into a practical form. The object of the inquiry was twofold: first, to determine with all possible accuracy the date of the comet's perihelion; secondly, to trace backwards the course of this famous comet and to identify its several returns. The result for the first is given in an "Essay on the Return of Halley's Comet," in which the predicted time is given as 1910 April 16·61, which is 3·03 days earlier than the actual observed time. The authors remark: "At least two days of this error must be attributed to causes other than calculation or errors in the adopted positions and masses of the planets."

The historical research was carried back revolution by revolution until the recorded appearances had been identified with certainty as far back as 240 B.C.

For this work the authors were awarded the Lindemann Prize of the Astronomische Gesellschaft, and both received the degree of D.Sc. from the University of Oxford.

The method developed for the calculation of the path of Halley's comet was used with equal success by Cowell and Crommelin in predicting the path of Jupiter's eighth satellite, where because of its great distance from Jupiter the solar perturbations were extremely large.

The essay on Halley's comet though perhaps the most spectacular was by no means Crommelin's most useful work. Numerous short astronomical papers are to be found in *Monthly Notices*, the *Journal* of the B.A.A., *Nature*, *Knowledge*, the *Observatory* and other publications.

For nearly ten years (1898–1906) he computed the ephemerides for physical observations of Mars, Jupiter and Saturn, and of the Moon, that formerly appeared in the *Monthly Notices*, till in 1907 this work was taken over by the Nautical Almanac Office.

Not the least valuable of his contributions to astronomy is the record of comets and minor planets which appeared month by month in the *Observatory* and in the *Journal* of the B.A.A., and the "Notes on the Discovery of Comets and Minor Planets" in the Council's Annual Report. In these he gives a synopsis of the special points of interest together with a Table of Elements of Cometary Orbits published in the preceding year. Anyone reading his Notes cannot fail to be impressed by the enormous amount of care and research involved; and this over a period of more than forty years.

Crommelin was keenly interested in eclipses of the Sun and the Moon, and was generally appealed to for information as to the circumstances of solar eclipses at the various observing stations selected. He took part in solar eclipse expeditions organized by the British Astronomical Association in 1896, 1900 and 1905, and in 1919 was invited by the Joint Permanent

Eclipse Committee to take part in the expedition to Brazil where the problem set was to determine the amount, if any, of the deflection of light in the gravitational field of the Sun. He observed with a 4-inch lens of 19 feet focus and obtained seven excellent photographs, the results from which proved the predicted deflection beyond question.

Crommelin was a Christian gentleman, modest and unassuming, careless of appearance but always courteous. A Protestant in his youth, after taking his tripos he stayed on at college reading for Holy Orders in the Anglican Church, but about this time became unsettled in his religious convictions, ultimately entering the Roman Catholic Church in 1891. All who knew him will remember him as an earnest and devout Catholic combining simple faith and piety with high scientific achievement.

A great reader, his knowledge was wide, almost encyclopædic. A ready and fluent speaker, he was always welcomed and listened to with keen appreciation whenever he spoke, whether at the meetings of the R.A.S. or the B.A.A., or at the numerous public lectures on astronomy which he gave for nothing. He was fond of lecturing, and juvenile audiences gave him great pleasure, as he had a gift for presenting his facts in the simple form which could be understood by his hearers.

Whilst at college he was a member of the University shooting team and shot for the University at Bisley. Though not an athlete he was fond of walking and swimming, was much interested in sport, and rarely missed seeing the University Boat Race from the towing path at Mortlake.

He married in 1897 Letitia, daughter of the Rev. Robert Noble, and had two sons and two daughters. His wife died in 1921, and in 1933, through a tragic mountaineering accident, he lost his elder son Claude and younger daughter Philomena. He leaves a younger son Peter, who is a Catholic priest, and a daughter Andrina. His colleagues and friends will not soon forget the assistance, whether in friendly criticism or advice, which he so generously rendered. He served on the Council from 1906 to 1932, was Secretary from 1917 to 1922 and President 1929, 1930.

He was elected a Fellow of the Society on 1888 November 9, so that for over fifty years he was a Fellow. C. R. DAVIDSON

HENRY PERCY DOUGLAS. Vice-Admiral Sir H. Percy Douglas, formerly Hydrographer of the Navy, died on 1939 November 4 at Dover, where since the outbreak of war he had been serving as Commodore Superintendent to H.M. Naval Dockyard; a few days later, according to his wish, his ashes were scattered over the sea.

He was born on 1876 November 1, being the second son of Admiral Sholto Douglas, C.B., and it was natural that he should follow his father's footsteps and enter the Navy; he duly entered *Britannia* as a cadet in 1890, and from then until 1896 his service afloat and on shore did not differ materially from the normal life of a cadet and midshipman. The first indication of his specialised interest in surveying and pilotage, which was later to lead him to the appointment of Hydrographer, came in 1896 when he took "firsts" in seamanship and pilotage in his passing-out examination;

he was appointed as Sub-Lieutenant to H.M.S. *Stork* in the Red Sea and the Mediterranean, this being the first of many surveying ships in which he served at various times in all parts of the world. In 1908, as Lieut-Commander, he was given his first command—the surveying ship *Waterwitch* in the China seas.

Two years later, in 1910, Douglas was appointed Superintendent of Charts at the Admiralty, a post that he held until early in the Great War. A high standard of administrative ability and technical knowledge is demanded in this important branch of the Hydrographic Department, where the results of hydrographic surveys from all over the world are collated to produce the magnificent series of charts which are not only famed the world over but are used wherever ships sail. A few months after the outbreak of war Commander Douglas (he had been promoted Commander in 1910) was sent to the Dardanelles for special service on the staff, where he served with distinction, being commended for service in action. During his active service he was promoted Captain, and in April 1917 was ordered back to the Admiralty to serve as the first Director of the Naval Meteorological Service ; although he only remained there for less than a year, he left no doubts as to the essential nature of that service. For the remainder of the war he joined the staff of Vice-Admiral Roger Keyes, commanding the Dover Patrol, and took a leading part in the many technical problems confronting the Navy at that time, culminating in the details of the attacks on Zeebrugge and Ostend. For this work he was gazetted C.M.G., and received the Italian Medal for Military Valour and the Belgian Order of Leopold.

After the war Captain Douglas served for five years as Assistant Hydrographer, during which time he personally took charge of surveys in the West Indies. In 1924 he was appointed Hydrographer, in which capacity he remained until 1932, the extension of the normal period of service to eight years being a well-merited tribute to the value of his services. Although the post of Hydrographer is largely administrative, Douglas found time to serve on many technical committees and his knowledge and experience were of great assistance in many directions ; his work on the *Discovery* Committee for Antarctic Research was particularly valuable. During his term of office, and largely due to his interest and foresight, the echo-sounding apparatus, which is now so successful, was introduced. He was promoted to Rear-Admiral in 1927, retired from the active list in 1929, and promoted Vice-Admiral, retired, on 1931 June 1 ; he was created K.C.B. in 1933. After relinquishing the post of Hydrographer, he was Chairman of the Dover Harbour Board until he was recalled, at the outbreak of war, to the post he held at the time of his death.

The Hydrographer of the Navy plays an important part in the development of official astronomy, as he is the link between the Royal Observatories at Greenwich and the Cape on the one hand, and the Board of Admiralty on the other. Thus the fortunes of the observatories are bound up in no small measure with the extent of the active sympathy with and interest in astronomy of successive Hydrographers ; it can be said that there has usually been a very favourable understanding between Greenwich and the

Admiralty, and during his period of office Douglas, a true naval officer and a man of science, was no exception to the rule. He was elected a Fellow of the Society on 1919 April 11, and took an active interest not only in the astronomical and geophysical activities of the Society, but also in the more social side. He will be missed by many astronomers for his bluff good humour and genial companionship.

(Many of the facts of the above notice are taken from *The Times* obituary notice.)

JOHN WILLIAM DURRAD died on 1939 December 29 while in his eighty-sixth year. He was born in Leicester on 1854 October 25, and lived in that city the whole of his life, following the occupation of a leather merchant. At an early age he became interested in astronomy, which became for him a lifelong hobby. Before he was twenty-one he had already studied and taken a great interest in astronomy, and in that year (1875) he discovered several new crevasses on the Moon near Gassendi. Some finished drawings that he made about this time were used by Goodacre in his book on the surface formations of the Moon. For many years he was connected with the astronomical section of the Leicester Literary and Philosophical Society, and the small observatory in the garden of his home was a centre for all interested in astronomy. He had many interests other than astronomy: he was a water-colour artist of no mean standing, and exhibited up to the year of his death ; he was a keen lover of music, and played the 'cello in the Leicester Orchestral Union for over twenty years. His interest in music was shared by his wife, Elizabeth Hodgkins, who was herself an accomplished pianist ; they were both well known in local musical circles. He is survived by two sons and one daughter.

He was elected a Fellow of the Society on 1876 March 10, and was one of the oldest as well as one of the longest serving Fellows.

FRANK WATSON DYSON. The death of Sir Frank Dyson has removed from our midst one who has played an outstanding part in the progress of astronomy. His official position brought him into contact with most astronomers not only in England but from all countries of the world, while his simple and engaging personality endeared him to all. The loss to our Society is a heavy one. He was a Fellow for forty-five years, and for a total of thirty-seven years he served on the Council, holding office as President, Vice-President, Secretary and Treasurer. As he attended the meetings regularly he was well known to many Fellows, by whom his death will be felt as a personal loss.

Frank Watson Dyson, son of the Rev. Watson Dyson, a Baptist minister, was born at Ashby, in Lincolnshire, on 1868 January 8. His early life, however, was spent in Yorkshire, and he attended Bradford Grammar School. In due course he was elected to an entrance scholarship at Trinity College, Cambridge, where his successes were many. In 1888 he was awarded the Sheepshanks Exhibition in Astronomy. The following year he was placed second in the list of the Mathematical Tripos (the senior being our Fellow

Sir G. T. Walker). Thereafter he commenced research work in problems of gravitational attraction, and in 1891 he was awarded a Smith's Prize and elected a Fellow of his College. In 1892 he became the second Isaac Newton Student, the first being R. A. Sampson, who succeeded him as Astronomer Royal for Scotland.

His first paper, published in the *Quarterly Journal of Mathematics*, dealt with the "Motion of a Satellite Round a Spheroidal Planet." Later he published in the *Philosophical Transactions* a paper "On the Potential of an Anchor Ring." This work done at Cambridge indicated his interests.

In 1894 H. H. Turner, Chief Assistant at the Royal Observatory, Greenwich, was elected Savilian Professor of Astronomy at Oxford, and Dyson was appointed to the vacant post at Greenwich.

The appointment of a young man who had hitherto had no practical experience of astronomical observations to an important post at a great observatory may not appear a natural one, and at times such appointments have given rise to considerable criticism, but it must be admitted that such appointments at Greenwich have generally been justified by the results. It was particularly so in the case of Dyson. From the time of his appointment, throughout his period as Astronomer Royal for Scotland (1906–10) and finally as Astronomer Royal at Greenwich (1910–33) he devoted himself continuously to the advancement of practical astronomy. He was well aware of the necessity of having the original observations made with every possible care, for on them the accuracy of the final results must depend. Therefore while he as Astronomer Royal followed the plan of appointing chief assistants direct from Cambridge, he was always anxious to have men of a practical turn of mind, and he stressed on them the importance of personally taking part in routine observations. He often expressed the view that it was the duty of an observatory to get observations, and up to the time of his retirement he assisted in this way, often playing the humble rôle of recording observations made with the transit circle or making exposures with the Cookson floating telescope for latitude variation when such observations were badly wanted.

When Dyson went to Greenwich in 1894 work on the Astrographic Catalogue had already commenced, and the methods for measuring plates and reducing them had been developed, a work in which his predecessor Turner had played an important part. It does not seem to have been fully realised at some observatories when the photographic part of the work was commenced that it was essential to obtain accurate places of the reference stars. This, however, was not the case at Greenwich, and although the zone allotted to it, from the Pole to declination $+64°$, had been pretty well observed in the past, a new series of observations was carried out for the determination of the places of the reference stars. Dyson seems to have paid particular attention to the derivation of the plate constants. Preliminary values were calculated from star places already available. He found that when the usual six constants (three in each co-ordinate) were calculated from old star places the theoretical relations between them were not nearly so closely satisfied as when modern Greenwich observations were used. This indicated that the

geometrical conditions were more closely satisfied at the telescope than shown by the constants based on poor places of the reference stars. It was possible to assume a standard scale for all plates and one orientation for both co-ordinates, thus reducing the number of independent constants for each plate from six to three and greatly increasing the accuracy of their determination.

The work in connection with the Astrographic Catalogue was not the most important work done by Dyson as Chief Assistant at Greenwich (1894–1905). His attention was attracted to the motions of the stars, not only in connection with the astrographic reference stars, but also in the preparation for publication of the Greenwich Catalogue for 1890. This included the re-observation of many circumpolar stars which had been observed by Stephen Groombridge at Blackheath some eighty years earlier. In the report of the Astronomer Royal (Sir William Christie) for 1899 we read: "It is proposed now to undertake the determination of the proper motions of all the Groombridge stars; but before doing this it is advisable that Groombridge's observations should be re-examined in view of the large systematic errors in R.A." A year later he wrote: "A new reduction of Groombridge's observations has been undertaken and is steadily progressing." The work was pushed ahead rapidly and published in 1905 under the joint names of Dyson and W. G. Thackeray. There can be no doubt that Dyson played the leading part in this extensive work, although it was an official production of the Royal Observatory, Greenwich. The observations, some 27,000 in number, were completely re-reduced from the original records, the work involving such details as determination of division errors, wire intervals and the daily instrumental errors. The ledgers were published in detail and combined to a catalogue of 4239 stars for the epoch 1810. This is on the system of Newcomb's Fundamental Catalogue. In combination with the latest Greenwich observations, proper motions for all the Groombridge stars were derived and comparisons were given with the Radcliffe Catalogue for 1845 and the various catalogues of the Astronomische Gesellschaft.

These proper motions constituted a most important contribution to our knowledge in so far as they more than doubled the number of well-determined motions and extended them to fainter stars. Hitherto accurate motions had been derived only from the bright stars observed by Bradley. The Groombridge stars have a mean magnitude of 7·0, while a considerable number of them are between magnitudes 8 and 9. Dyson and Thackeray discussed the motions they had determined with reference to magnitude, spectral type and size of proper motion. A correction to the constant of precession was derived. Many results now well known, but only just coming to light at that time, were confirmed: such results as the dependence of the solar apex on the magnitude of the stars considered, and the connection between the average size of the proper motion, the spectral type and the distance from the Milky Way. The fact that the latter would influence the derived position of the solar apex was noted.

From 1906 to 1910 Dyson was Astronomer Royal for Scotland and Professor of Astronomy at Edinburgh. The work of Edinburgh Observatory

was extended to include the observation of double stars near the Pole (unobservable at Greenwich with the 28-inch equatorial) and the measurement of astrographic plates taken at Perth, in Western Australia. Dyson continued his interest in proper motions and published papers on stars of large proper motion. In particular he showed that star streaming, which had been announced by Kapteyn in 1904 and was not readily accepted by some astronomers, was confirmed by stars of large proper motion. For these stars the results could not be seriously influenced by errors of observation, as might be the case in stars of small proper motion. He also discussed the systematic motion of the stars as indicated by the cross proper motion of the Bradley stars.

In 1910 Dyson was appointed Astronomer Royal in succession to Sir William Christie, and from then till his retirement in 1933 a description of his work is largely a description of the work of the Royal Observatory at Greenwich. It is not possible in a notice of this nature to go into all the work accomplished at Greenwich during that time, and Dyson himself would have been the last man to claim the work as his own. He, indeed, was always foremost in attributing the success of the institution to the ability and industry of the staff. He gave direction to much of the work, but at the same time readily listened to the proposals or suggestions of others. The General Index to the *Monthly Notices* for the years 1911–31 gives references to only fourteen papers by Dyson himself and seventeen in collaboration with members of the staff. Fellows who attended the meetings of the Society during these twenty years will be surprised that these numbers are so small. The explanation is that he did not claim personal credit for work done at the observatory. During the same period there were many papers communicated to the Society by members of the Greenwich staff and many others, simply communicated by the Astronomer Royal.

In 1910 the time was ripe for an extension of the work of the Royal Observatory in new directions. In the U.S.A. Schlesinger had shown how accurately stellar parallaxes could be determined by photographic methods, and Pickering had established standard magnitudes for a sequence of stars in the neighbourhood of the North Pole. Within a very short time of Dyson's return to Greenwich parallax observations were commenced. In photographic photometry several programmes were put into operation—standardisation of magnitudes in the Astrographic Catalogue and the Franklin-Adams Charts, and the determination of magnitudes in the northern Kapteyn areas. The work involved as well as the overcoming of technical difficulties was naturally done by other hands than his, but Dyson played the part of an effective Director of the observatory with his knowledge and encouragement. In 1911 the Cookson Floating Telescope was lent to Greenwich—a loan which has been renewed at intervals as required—and observations for the determination of latitude variation have been regularly carried on since then. This enabled work with the reflex zenith tube to be discontinued.

Dyson's principal contributions to astronomy were connected with the reduction and discussion of meridian observations. We have already noted his work at Greenwich as Chief Assistant, and after he returned as Astronomer

Royal he spent much of the time free from administrative duties in the preparation of the results for publication. He was specially interested in the motions of the stars, and paid particular attention to the systematic differences between the various catalogues. The programmes of observation with the Transit Circle were carefully chosen, and included the Backlund-Hough Stars (1915–21), followed by the brighter stars between $+32°$ and $+64°$ and finally stars between the Equator and $+24°$. The first of these showed how important to him were the regular observations of the fundamental stars, while the others completed at Greenwich the observation during the present century of all the stars down to magnitude 7·5 (or fainter) north of the Equator. This enabled the proper motions of all these stars to be determined, and the date of the preface to the second Greenwich Catalogue for 1925 shows that he was engaged in this work till the day of his retirement. Dyson realised that the Transit Circle at Greenwich which had been in use since 1851 was not up to the highest modern standard, and he long thought of a new one. But the difficulties of the post-war period held him back from pressing this need. When finally he approached the Admiralty and obtained sanction for a new instrument his tenure of office had not long to run. But he had the satisfaction of seeing the work of construction well in hand and the new building in course of erection.

We have already noted how Dyson found the work of the Astrographic Catalogue started when he first went to Greenwich. When he returned he found both the Catalogue and the Charts published. Many observatories have found this more than sufficient to tax their strength, and consequently they have not so far been able to reap a harvest comparable with the labour expended. Greenwich has been able to follow up the publication of the rectangular co-ordinates of the stars with more interesting work. By 1913 the spherical co-ordinates of the brightest stars had been published together with a comparison of the positions with those derived from meridian observations. Dyson's interest in proper motions directed the work into new channels, and first of all proper motions were determined for all the brighter stars, using photographs of later epoch where early meridian observations were lacking, and finally all the stars of the Astrographic Catalogue were measured for proper motion on photographs taken at an interval of about thirty years. The derived motions were naturally discussed with reference to spectral type, etc.

Dyson was keenly interested in total eclipses of the Sun. As Chief Assistant he observed the eclipses of 1900 in Portugal, 1901 in Sumatra and 1905 in Tunis. He was fortunate in having good weather at these eclipses, and his observations contributed to the determination of the wave-length of the coronal lines as well as the identification of elements in the chromosphere. He witnessed the eclipses of 1912 in Paris, 1927 in Giggleswick and 1932 in U.S.A., again under good conditions. But as Astronomer Royal and as a member of the Joint Permanent Eclipse Committee he did splendid work in arranging for expeditions to be sent from England, and especially from Greenwich, to observe the various total eclipses between 1911 and 1932. His greatest success was that of 1919. In a short paper to the *Monthly*

Notices published in 1917 he drew attention to the opportunity of testing the deflection of star-light in the Sun's gravitational field. Photographs taken with the astrographic telescope at the eclipse of 1905 showed three or four stars, and proved that that telescope was suitable for testing the predicted displacement. By far the best field of stars along the whole length of the ecliptic lies in the region which the Sun passes through on May 29, and by great good fortune a total eclipse with six minutes' totality in regions where clear skies were probable was due to take place on that very day in 1919. Such a favourable eclipse will not occur on the average more frequently than once in a thousand years.

"In 1918, in the darkest days of the war, two expeditions were planned, one by Greenwich Observatory and one by Cambridge, to observe, if the state of civilisation should permit when the time came, the eclipse of May 1919 with a view to a crucial test of Einstein's generalised relativity. The Armistice was signed in November 1918; the expeditions went and returned, bringing back news which changed, and that irrevocably, the astronomer's conception of the nature of gravitation and the ordinary man's conception of the nature of the universe in which he lives. If the credit of this achievement is to be divided between Sir Frank Dyson and Professor Eddington I frankly do not know in what proportion the division should be made. To my mind, however, it is not so much an occasion for sharing out credit as for attributing the whole credit to each, for if either had failed to play his part, either from want of vision, of enthusiasm, or of capacity for seizing the right moment, I doubt if the expeditions would have gone at all, and the great credit of first determining observationally what sort of things space and time really are would probably have gone elsewhere." *

Astronomers have observed the Einstein displacement at subsequent eclipses but always under conditions of the greatest difficulty on account of the faintness of the stars, so that even with improved technique the small outstanding residuals will not be easily accounted for. Dyson continued his interest in eclipses, and after his retirement carried out the plan he had formed many years earlier of writing a book on eclipses. (In the parts dealing with modern theories of spectra he was assisted by Dr. Woolley.)

During Dyson's tenure of the office of Astronomer Royal technical advances in various directions led to considerable changes at Greenwich. This was particularly the case in the time service, a rather important work for a national observatory. In 1912 the first wireless time signals were received from Eiffel Tower. Wireless time signals made possible a much closer comparison of time determinations made at different observatories than had previously been possible and unexpectedly large differences were found. Although considerable improvement has been made in the actual time determinations, the greatest advances have been in the means of time keeping and time distribution. The standard clock had been in use for nearly half a century. It was undoubtedly a very fine piece of workmanship, but it was not compensated for temperature and pressure changes with anything like modern accuracy. Fortunately Mr. W. H. Shortt had designed a

* Sir James Jeans, *M.N.*, **85**, 677, 1925.

new type of clock known as a free pendulum clock. In 1925 the first Shortt clock was brought into use, and its value being at once realised clocks of this type were procured for maintaining both sidereal and mean time. For distribution of time to the public the system of sending out six pips was inaugurated, and for scientific purposes powerful rhythmic signals were sent out twice daily from Rugby. Dyson took a keen interest in clock making, and became President of the British Horological Institute, which awarded him its Gold Medal in 1928.

The magnetic work of the observatory underwent various changes. A new magnetograph house with improved recording instruments was erected in the Magnetic Enclosure before the war. The approaching electrification of the local railways necessitated the removal of all the magnetic work from Greenwich, and a new Magnetic Observatory was erected at Abinger in 1924.

As a consequence of his official position Dyson was called upon to assist in the work of many committees and this took up much of his time. After the war the whole scheme of international co-operation had to be rebuilt. He took his full share in this work, going to Brussels in 1919 for the meeting at which the International Research Council (now the International Council of Scientific Unions) was formed. The International Astronomical Union soon brought astronomers into closer international co-operation than they had ever been before. Dyson attended all the meetings of the Union from 1922 to 1935, taking an active part in the work of the various commissions as well as of the executive committee. His work for the Union as well as for astronomy in general was fittingly recognised by his election as president for the years 1928–32.

He undertook a considerable amount of work in connection with committees of the University of London and educational institutions generally. For a number of years he was the only astronomer amongst the Trustees of the Radcliffe Observatory, and he had a good deal of responsibility in connection with the removal of the observatory from Oxford to Pretoria. Locally he was called on to serve on many charitable organisations, and he was ever willing to serve in any good cause. During the war he raised considerable sums of money for the Red Cross by garden parties at the Royal Observatory, a means of raising money which was afterwards continued on behalf of local hospitals.

There is no doubt that Dyson enhanced the prestige of the Royal Observatory in the eyes of the public both in the neighbourhood of the observatory and in the country at large. A quite unexpected recognition of his services came a few years before he was due to retire. It was intimated to him that Mr. William Johnston Yapp, a gentleman previously unknown to him, wished to commemorate his work in some signal manner—by a gift of a large instrument to the observatory. Dyson was at the time thinking more of the needs of the observatory in the form of a new transit circle and in the general advancement of astronomy (not necessarily at the Royal Observatory) than in some permanent memorial to his own work. But the donor made it plain that the gift must be in recognition of Dyson's work

and must take the form of a large instrument for the Royal Observatory. After careful consideration it was decided that a 36-inch reflecting telescope was the largest which could be efficiently used in a climate such as that at Greenwich, and for its construction and housing Mr. Yapp offered the £15,000 estimated to cover the cost. The gift was gratefully accepted by the Lords Commissioners of the Admiralty and plans were speedily prepared. The inaugural ceremony took place on Visitation Day, 1934, when the new telescope was formally accepted by the First Lord of the Admiralty in the presence of both Dyson and the donor.

Dyson received many honours in recognition of his scientific work. He was awarded a Royal Medal of the Royal Society in 1921, the Bruce Medal of the Astronomical Society of the Pacific in 1922 and the Gold Medal of our Society in 1925. He received honorary degrees from many universities, including those of Cambridge, Oxford and Edinburgh, and several colonial universities. He was created a Knight Bachelor in 1915 and a K.B.E. in 1926.

Those who knew him best will not claim that he was a great administrator if by that is meant a man skilled in the ways of diplomacy. He never exaggerated his case or presumed on the ignorance of others. When he had to ask for money for any project he never asked for more than what he himself was convinced was necessary. He was transparently honest. The result was that he probably sometimes got his way where a more forceful man might have failed. He was a most successful head of an institution, carrying on scientific work where complete confidence between all the members of the staff is essential. He did not presume to be an authority on instruments, but he recognised mechanical ability in others and its great importance for successful work in an observatory. He was as willing to co-operate with those below him as above him in status or knowledge. To all members of the staff he gave free scope. He tried to interest all in the work they were doing and by his own enthusiasm imparted enthusiasm to others. It was by these methods that so much was accomplished while he held office at Greenwich.

Dyson married Caroline Bisset Best, daughter of Dr. Palemon Best, in 1894. The marriage was a most happy one. They had a family of two sons and six daughters who, with a number of grandchildren, all survive. With the care of a large family Lady Dyson had a very busy life and for long was unable to accompany her husband abroad on expeditions or to attend conferences. But towards the end, as the family grew up, she was able to travel with him. At all times she was heart and soul in his work, and as all astronomers were his friends so were they hers. Large is the number of those who will recall the friendly, natural welcome which they received in the family circle at Flamsteed House. Lady Dyson predeceased her husband by a few years, and he never really recovered from the loss of her companionship.

Till the last few years of his life Dyson enjoyed good health. After he retired he carried on active work both on scientific committees and in connection with charitable organisations. He made trips to South Africa in

1933 and 1937 and to America in 1935. For the last two years he knew that his strength was failing and spoke of doing things in the future if he were still alive. Early in 1939 he left England to visit a son in South Africa and a daughter in Australia. When he reached South Africa he was far from well and had apparently had a slight stroke. He was seriously ill before the ship got to Australia, and most of the time he spent in Sydney in a nursing home. No immediate danger for his life was felt when he left Australia, although it had been decided to omit the projected stay in South Africa. However, he had a serious relapse soon after leaving Australia and he died and was buried at sea on May 25.

He was elected a Fellow of the Society on 1894 April 13.

J. JACKSON

WILLIAM MOSES FELDMAN was born on 1880 November 17 at Pinsk, which at that time was included in Russia but at a later date belonged to Poland, and now again is Russian. Both on the paternal and also on the maternal side he belonged to a family of Rabbis, and with such a family history it is easy to understand that his parents fully intended that their only son should enter *volens nolens* the Jewish ministry, and to this end he received the traditional training in Hebrew and Rabbinics until he was thirteen years of age. At this time he was carried to London and, entering the Jews' College, his Talmudical studies were continued and intensified. It seemed, indeed, as if destiny had marked him for a Rabbinical vocation, but as his mind developed and his outlook became wider he broke from the leading strings, and at the age of nineteen or twenty his great ambition found expression and he was entered at the London Hospital for his medical training. Even at this early age his sympathetic nature longed to alleviate some at least of the physical ills under which we all sooner or later stumble and collapse. He qualified to practise his art in 1904. Another seven years of hard work gave him his M.B. and B.S. in 1911. On 1913 September 24 he married his cousin, Hilda Kate Feldman. Yet a little while and the Great War being over, he wrote his first book on the *Principles of Ante- and Post-Natal Child Physiology*, and in the year of its publication (1920) gained his M.D.(Lond.).

By this time he was a very successful and popular medical practitioner. In 1927 his second effort as an author appeared on *Ante- and Post-Natal Child Hygiene*. These two volumes are standard works on his chosen subjects. Another book on the *Jewish Child* is full of interest for the layman, while it reveals the Hebrew and Talmudic scholarship of the author.

Professor Sampson in 1931, the Astronomer Royal for Scotland, wrote an appreciative preface for Feldman's *Rabbinical Mathematics and Astronomy*. This octavo volume of 232 pages is the result of several years of research in British and continental libraries, and was reviewed in *J.B.A.A.*, **43**, 31–33. His *Biomathematics* went to a second edition in 1935—it covers a field hitherto neglected—and in this year he gained his major professional distinction, the coveted F.R.C.P.(Lond.). He was a member of the British

Astronomical Association, and in 1934 was duly elected F.R.A.S., when he had been a Fellow of the Royal Society of Edinburgh for seven years.

His numerous professional writings on a wide variety of medical subjects may be found in British and American journals. Feldman was Senior Physician to St. Mary's Hospital, Plaistow, and on the Council of the United Synagogue and Jews' College. Professor Selig Brodetsky of Leeds University, a lifelong friend who supplied much of the material for this notice, permits me to quote the final sentence of his: "His books on Mathematics and Astronomy in Rabbinical writings show a deep knowledge of mathematics as well as a very competent knowledge of astronomy."

Our Fellow William Moses Feldman died very suddenly and unexpectedly of his first heart attack on 1939 July 2, leaving a widow, two sons and a daughter. He is missed in many circles, and especially by all those for whom he worked so untiringly.

In his library he was a most pleasant companion, always helpful in problems submitted to him by his friends.

FRANK ROBBINS

DAVID ROSS FOTHERINGHAM, who had been a Fellow for nearly thirty years, died at his residence, "Mendip," Kennington, Ashford, Kent, on June 30.

Born on 1872 December 11 at Tottenham, the eldest son of the late Rev. David Fotheringham, for forty years minister of St. John's Presbyterian Church, Tottenham, and Moderator of the Synod of the Presbyterian Church of England in 1912, he was educated at the City of London School and at Queen's College, Cambridge, where he graduated in 1895. In the following year he was ordained, and he served with the Philhellenic Legion in the Greco-Turkish War of 1897, subsequently being made a Knight of the Order of the Holy Redeemer of Greece. He then accepted a curacy in Camden Town, which he held until 1912, when he was offered the living of Charing, in Kent. Here he remained, fulfilling in ample measure the duties of a country clergyman, until the spring of 1939, when he was compelled through ill-health to resign.

Fotheringham was a man with a great many divers interests. His interest in astronomy dated from an early age, and he kept up a voluminous correspondence on the subject with his younger brother, the late J. K. Fotheringham, Reader in Ancient Astronomy and Chronology at the University of Oxford; his letters being full of valuable suggestions and comments on his brother's work. It is noteworthy that his parish magazine always contained a few notes on the more prominent stars that his parishioners might notice during the month either late at night or in the early morning on their way to work. He was also keenly interested in the controversy on the fixed date of Easter, which arises from time to time and makes little progress. A little brochure entitled *The Date of Easter*, which he produced some years ago, has received much praise from many quarters for the lucid way in which he states the case, while omitting no reference to the many abstruse and varying authorities that have to be cited.

A man of literature and a poet in a humble way, he was often referred to as "Charing's Literary Vicar." Whenever a few stanzas were needed for some topical event, for the introduction to the Village Play, or for some special service in church, the Vicar's muse always responded. He also published a few poems, some of which are included in *War Songs of the Greeks*. His connections both with Greece and poetry brought him naturally into touch with the Byron Society, of which he became the keen organising secretary for many years. Another interest was "King Charles the Martyr," and he organised the annual service at the statue of King Charles in Trafalgar Square in January every year.

Fotheringham suffered from deafness, the result of a bad attack of scarlet fever in his younger days. For the last twenty years of his life he was stone deaf, and all attempts at a cure had to be given up. This brought out the courageous side of his character. None of his interests were dropped. Every difficulty was overcome, and it was good to see the trouble that even his poorer and less-educated parishioners would take to write a few words to the Vicar on his ever-ready pad in lieu of conversation. Although he was never an adept at lip-reading, he was remarkably quick at picking up an idea and following a conversation. Even as chairman at a meeting a few scribbled words and a gesture would give him the substance of what was going on and he was seldom at fault.

So the chapter of peaceful life at a country vicarage has come to a close after more than a quarter of a century, but a great many outside friends and admirers join with the parishioners of Charing in mourning the passing of a saintly pastor with unusual gifts.

He married in 1902 Mildred, the daughter of George Taylor of Bakewell, Derbyshire. They had one daughter.

He was elected a Fellow of the Society on 1910 December 9.

E. H. LONGSDON

SIR PARK GOFF, Bt., K.C., died at Cannes on 1939 April 14, at the age of sixty-eight, after a distinguished career. He was founder and first President of the Anglo-Baltic States Society, and for many years he sat as a Unionist Member of Parliament.

Born on 1871 February 12, son of the late Colonel Bruce Goff and grandson of the late Sir John Goff, of Goff's Oak, Essex, and Goff's Place, Sussex, he was educated at Marlborough and at Trinity College, Oxford. He graduated in Jurisprudence, and was shortly afterwards called to the Bar; he took silk thirty years later. He contested his first election in 1911, but did not succeed in being elected to the House of Commons until 1918; from that time until 1935 (apart from a short break from 1929 to 1931) he was a most active M.P., holding in succession a number of minor posts and serving on numerous Select and Parliamentary Commissions, mainly connected with road and traffic problems, parliamentary procedure and commercial conferences. He took a leading part in the work of the many committees of which he was a member, and his duties took him at various times to most countries of Europe and America; in particular in 1923

the Speaker appointed him President of the Parliamentary Mission to the new Baltic Republics of Estonia, Latvia and Lithuania, and he never ceased to take the closest interest in these countries.

During the Great War he served as honorary King's messenger with great distinction, and was knighted in 1918; his baronetcy of Goff's Oak was created in 1936, and as he was unmarried it now becomes extinct. In the course of his work abroad he was honoured by a number of foreign countries, and he held, among others, Orders of the three Baltic States to whose well-being he devoted so much of his time and interest.

He was elected a Fellow of the Society on 1916 February 11; although keenly interested in astronomy, it was but one of his several scientific interests, and it is not surprising, in view of his busy and full life, that he made no contributions to the Society's publications.

HERBERT HEDLEY, the eldest son of Canon Hedley, was born on 1859 October 29 at Masham, in Yorkshire, and died on 1939 October 16. After obtaining scholarships for Eastbourne College and Trinity College, Cambridge, he read Mathematics, in which he graduated with brilliant distinction. On graduation his inclination led him to Auckland Theological College, Co. Durham, where he studied for Holy Orders. In due course he was ordained, and held in succession the benefices of Mickley (Ripon), Masham and Nackington; he also held foreign chaplaincies in Algiers, Valeseme and Malaga. Eventually he retired to Hythe, where he acted for a short time as Assistant Curate to the Rev. Canon Galpin.

Hedley's interest in astronomy did not materialise until the later years of his life, but he devoted the last twenty years, including the time of his foreign chaplaincies, to astronomical studies, writing articles from time to time in different papers and attending the meetings of the Society. His greatest pleasure was in lecturing, and he used to travel about Kent or even further afield lecturing on his favourite interest; on several occasions he lectured on "Stars" at Eton College and other schools. When time permitted he spent long hours exploring the heavens with his 4-inch telescope, but his observations were always of a general rather than a specialised character. His interest in astronomy was divided with that in microscopic work, and his early studies in botany and biology afforded him a great field of exploration.

He married Margaret Inglis Cosgrave in 1889; she was his devoted companion for more than forty-nine years, predeceasing him by but a year. Their only son lost his life in the Great War, and he is survived by one daughter.

He was elected a Fellow of the Society on 1926 February 12.

HENRY PARK HOLLIS was born on 1858 January 9. From Westminster School, where he received his early education, he went to Jesus College, Cambridge. He sat for the Mathematical Tripos and took his degree in 1880.

In November 1881 he became an Assistant at the Royal Observatory, Greenwich, his being the first appointment to the Staff to be made under Christie, who had then but recently been made Astronomer Royal. Hollis remained at Greenwich until his retirement in January 1920, a period of service which went back to the time when Airy's influence still remained. In the course of his duties it was his good fortune to be called upon to carry out many different programmes of work, and he dealt with each with characteristic energy.

At the outset Hollis took his share in the routine observations made with the Transit Circle and Altazimuth instruments, and for a time had charge of the reductions. Later he became associated with Maunder and assisted him with the solar and spectroscopic observations. In particular, Hollis was responsible for the measurement and reduction of a number of solar photographs which had been handed over to the Royal Observatory in order to complete the record of past years. He was also engaged on the preparation of the *Greenwich Ten Year Catalogue* (1880) in connection with which mention may be made of a paper contributed jointly by him and (Prof.) Turner—then Chief Assistant—to the *Memoirs* of the Society, entitled "Comparison of the Greenwich Ten Year Catalogue, 1880, with the Cape Catalogue, 1880." Hollis also contributed a paper to the *M.N.* (55, 71, 1895), "On a Comparison of some Places of Stars observed at Sydney with the Places of the same Stars as given in the Cape Catalogue, 1880."

Between the years 1890 and 1910 a number of longitude determinations were carried out at Greenwich. Hollis superintended the reductions and was himself one of the observers in the two determinations of the difference of longitude between Paris and Greenwich made in 1892 and 1902, and also in the Killorglin longitude observations of 1898. From the experience gained in carrying out the work Hollis acquired an extensive knowledge of the theory and practice of the transit instrument, and a number of articles bearing on the subject were contributed by him to *The Observatory* magazine.

In 1896 Hollis was placed in charge of the work of the astrographic chart and catalogue. He took over at the time when the routine measurement of the catalogue plates began, and he continued to supervise the work until his retirement. During the years which he devoted to this task he had the satisfaction of carrying through to a successful conclusion the Greenwich portion of the undertaking, as evidenced in the four volumes published and the photographic reproduction of the chart plates.

Outside his official duties Hollis was deeply interested in his chosen science, and over a long period contributed valuable articles to the *English Mechanic* which were of the greatest interest and use to amateur astronomers. From 1893 to 1912 he was one of the editors of *The Observatory* and later became astronomical correspondent to *The Times*. For many years he compiled the astronomical data given in *Whitaker's Almanack*. He was author of *Chats about Astronomy*—a book addressed to the general reader—and wrote that part of the History of the R.A.S. covering the decade 1870–80.

Hollis joined the B.A.A. on its foundation, was a valued member of its Council, and served as President in 1908–09.

After his retirement from the Royal Observatory Hollis continued to be as keenly interested as ever in all that went on in the astronomical world, and seldom failed to attend the meetings of the Society. He will be remembered by all who knew him as a quiet and courteous gentleman who had a deep knowledge of his subject and who was always willing to assist those who were interested in astronomy.

In 1882 he married Clara Susanna Clark, who predeceased him in 1932. He died on 1939 August 7 and is survived by one daughter and two sons. He was elected a Fellow of the Society on 1884 December 12, and served on the Council from 1909 to 1912.

P. J. MELOTTE

JAMES THOMAS JACKSON was born at Frankfort, in King's County, Ireland, and entered Trinity College, Dublin, in 1890, where he earned distinction in mathematics and also in experimental science. He obtained a Foundation Scholarship in Mathematics and an Honours Degree in the same subject, and first place at the Honours Degree examination in Experimental Science (Physics and Chemistry). His interest in astronomy seems to have been stimulated by Sir Robert Ball's lectures on that subject.

After taking his degree he passed through the Engineering School and practised as an engineer in Siam for three years, and afterwards in Ireland. In 1903 he was appointed Assistant to the Professor of Physics in Trinity College, Dublin, becoming later a Lecturer on the staff of the Engineering School, which appointment he held till his death. He was a member of the Institute of Civil Engineers, Ireland, and occupied successively the positions of Honorary Secretary and President.

He was a man of infinite kindliness and charm of manner, beloved by many generations of engineering students. To him past students came at difficult crises in their careers, rightly believing that his advice was more than ordinarily useful in directing them into the most promising avenues of professional service.

He married Elizabeth, daughter of Louis Damer Mulhall, and is survived by his widow and two sons, both civil engineers. His death took place on 1938 November 22.

He was elected a Fellow of the Society on 1909 January 8.

J. R. COTTER

ARTHUR EDWIN KENNELLY, a Fellow of the Society since 1893 June 9, was an electrical communications engineer of world repute. He was born at Colaba, near Bombay, India, on 1861 December 17, and died on 1939 June 18. In 1893 he married Julia Grice of Philadelphia, who predeceased him in 1939; they are survived by one son.

Kennelly was educated at schools in Great Britain, France and Belgium, mainly at University College School, London. At the early age of thirteen he heard a lecture by Latimer Clark on Submarine Telegraphy at the Albert

Hall, London, which attracted him to the career of a telegraphic engineer. He began work at fourteen as assistant secretary to the Society of Telegraphic Engineers, London (which afterwards became the Institution of Electrical Engineers), and a year later he started practical engineering work in the submarine cable service of the Eastern Telegraph Company ; he continued for eleven years to be occupied with the cables connecting England and India.

In 1887 he migrated to America, which became his home for the rest of his life ; he went to assist Edison, with whom he remained until 1894. Then followed a period in which he carried on practice as a consulting engineer. In 1901 he was appointed to the Professorship of Electrical Engineering at Harvard University : during the years 1913–23 he also held a professorship at Massachusetts Institute of Technology. He retired as Professor Emeritus in 1930.

His scientific work was mainly connected with his profession as a practical, consulting and teaching electrical engineer. He published no less than 28 books (18 in collaboration) and over 350 technical papers. Many of these were concerned with the application of complex quantities, and especially of complex hyperbolic functions, to alternating current problems.

One achievement which bids fair to keep his memory long in mind also associates his name with that of Oliver Heaviside, who likewise cultivated the field of electrical theory. The two men were in many ways remarkably different, but they had this in common : both attained to high scientific eminence through their contributions to a difficult and rapidly developing subject of great practical importance ; and both were largely self-taught, not having had any regular university education. Heaviside was doubtless the greater scientist, but his genius was combined with a difficult attitude towards the world ; Kennelly had *savoir faire* and agreeable manners, and in consequence his distinguished talents were rewarded by a prosperity never attained by Heaviside.

Their names are linked together in the designation "Kennelly-Heaviside layer," often applied to the lower of the main ionized strata in the ionosphere ; an alternative impersonal name is the E layer. In the early days of radio telegraphy it was found that radio waves travelled much farther round the world than the electrical theories then current would suggest. In 1902 first Kennelly, and later Heaviside (independently), suggested that this might be due to the existence of an ionized conducting layer in the upper atmosphere. This has since been confirmed ; at the time neither author seems to have been aware that the presence of such a conducting layer had been postulated about twenty years earlier by Balfour Stewart, on the evidence of the transient variations of the Earth's magnetic field.

Kennelly received an abundance of American and foreign honours and awards for his scientific and professional achievements. In his later life he also took a considerable part in international scientific gatherings connected with telegraphic and radio science and with electrical units : his personal charm and his linguistic gifts made him a valuable member of such gatherings.

S. CHAPMAN

ARTHUR EVERARD LEVIN was born on 1872 February 17 and was educated privately, afterwards taking up electrical engineering as a profession. On the outbreak of the South African War in October 1899 he enlisted in the London Electrical Engineers, and when the war ended in May 1902 he held a Government appointment for some time. Later he joined the firm of Mordey & Dawbarn, consulting engineers, and after some years he entered into partnership with Mr. Mordey. When he retired from his profession in 1928 he went to live at Selsey, where most of his astronomical work was done, partly with his 6-inch refractor, but more especially in the computational branch, in which he was keenly interested.

As an old Volunteer he remained with his unit when the Volunteers became Territorials, and was mobilised on 1914 August 5. He was on active service in France and Italy and was mentioned in dispatches in 1918. After demobilisation with the rank of Major in 1919 his interests turned to astronomy, and he was elected a member of the British Astronomical Association the same year. His interest and ability in computational work were quickly in evidence. In the 1920–21 session the Computing Section of the British Astronomical Association was formed, and in 1922 Levin was appointed the second Director—a position which he held with a few interruptions until his retirement in 1938. Astronomy owes him a deep debt for his work in connection with the Computing Section, to which he devoted so much time and patience both in doing computations himself and also in teaching the keen band of computers who rallied to his assistance. His own chief interest was connected with the phenomena of satellites, and he contributed numerous papers to the *Journal of the British Astronomical Association* and to the *Memoirs* on the phenomena of the satellites of Jupiter and Saturn. His first Presidential Address to the Association in 1931 dealt with the Mutual Eclipses and Occultations of the four Principal Satellites of Jupiter—a subject to which he had devoted a considerable amount of work and for which he had developed a number of convenient methods of computation, recorded in a *Memoir* published in 1934. In addition to his interest in the phenomena of satellites he contributed in other ways to the *Handbook of the British Astronomical Association*, especially in the computation of cometary perturbations. His last work in this department was undertaken in collaboration with J. G. Porter, his successor as Director of the Computing Section, and the method used by Cowell and Crommelin for Halley's comet was applied to Comet Pons-Winnecke during the two revolutions 1927–33 and 1933–39. The comet was rediscovered by Jeffers very close to its predicted position on 1939 March 17.

He was Secretary of the British Astronomical Association from 1921 to 1930, and served on the Council of the Society during 1931–32. In *M.N.*, **82**, 177, he contributed a paper, "The Slide-Rule as an Auxiliary to the Solution of Kepler's Equation," which showed a simple method for finding a solution of Kepler's equation to an accuracy of two or three minutes. Although his chief astronomical interest lay in computational work he did not neglect the observational side, and he took part in the observations of occultations with his 6-inch refractor. He went to Leyburn in

1927 to see the total solar eclipse which, unfortunately, was spoilt by clouds.

Levin had many astronomical friends. His courteous manner and ever-ready help to the younger amateurs requiring guidance will long be remembered. The British Astronomical Association received his 4-inch refractor as a gift early in 1939, and now it is announced that he has also left his 6-inch refractor and observatory at Selsey to the Association, as well as his library. His death took place on 1939 November 8 after an operation.

He leaves a widow and a son, the latter now serving in the Navy.

He was elected a Fellow of the Society on 1921 January 14.

M. DAVIDSON

ARTHUR WILLIAM LONG was born in Coleraine, Northern Ireland, on 1874 April 11. He emigrated to South Africa about 1900 and soon afterwards entered the service of Messrs. W. M. Cuthbert, boot manufacturers, with which firm he remained connected throughout his life. His work at first required him to spend much time travelling in the Karroo, and there the beauty and clarity of the night sky attracted his attention and started an interest in astronomy which was intensified in 1910 by the appearance of Halley's comet.

The general public interest aroused by Halley's comet led to the formation in Cape Town in 1912 of the Cape Astronomical Association, of which Long was a most active foundation member. The editor of the *Cape Times* (Sir Maitland Park) expressed a desire to publish a monthly series of astronomical notes, but stipulated that they must be accompanied by a chart of the evening sky. Long was ready to write the notes but for some time was puzzled how to prepare the map. He ultimately solved the problem in his own way; the first note and map appeared on 1913 June 28, and this was followed by an unbroken series until his death. These notes have been of great value in spreading a knowledge of astronomy throughout South Africa.

Long did a great deal to promote the welfare of the Cape Astronomical Association by assisting in all its activities. He purchased a 3-inch refractor and invited those interested to his home for observation and discussion. For some years he was an energetic observer of variable stars, using a 6-inch refractor at the Royal Observatory and sending over 4000 observations to Harvard. He never discovered a comet himself, but it was certainly due in great part to his encouragement that others (Skjellerup, Reid, Houghton, etc.) did so. On one occasion W. Reid, who had been searching fruitlessly for comets and was on the point of giving up the quest, noticed that Long had had a number of gummed labels printed with the words "Reid's comet" ready for insertion in his map. Reid was so impressed with this manifestation of faith in his ultimate success that he continued to search till success came and he went on to discover six comets.

Long acted on the committee of the Cape Astronomical Association, and its successor the Astronomical Society of South Africa, continuously. He was President of the Society when it welcomed the astronomical members of the British Association to South Africa in 1929. He also served con-

tinuously on the committee of the Society's journal, and indeed did a good deal of the editorial work although he did not wish his name to appear in the journal as editor. When the Society purchased a refractor for the use of members Long allowed it to be housed in his observatory.

He published an atlas, "The Constellations as Seen from South Africa," which has reached a second edition. A series of talks on astronomy prepared by him was broadcast to schools. He was continuously receiving, and enjoyed answering, queries from people all over South Africa. He was glad to think that in doing so he was helping to lead them to a deeper appreciation of the wonders of the universe.

Long had a serious stroke in August 1938 from which he made a partial recovery. He struggled on, always having the interest of astronomy at heart. His death on 1939 September 15 is a serious loss to popular astronomy in South Africa. He is survived by his widow, who took the keenest interest in his work, and indeed in everything connected with the Astronomical Society of South Africa.

He was elected a Fellow on 1921 January 14. R. WATSON

CHARLES NIELSEN was born at Hartlepool on 1857 November 2, and died at Stockton-on-Tees on 1939 June 7. Throughout his life he was connected with ships and shipping, and for the later part of his life he was a well-known shipowner. His interest in astronomy dated from an early age, and for many years he gave frequent lectures on Astronomy to local societies ; he was always ready to encourage the young in astronomical studies and did his utmost to increase the knowledge of the subject he loved. Comets and eclipses were his favourite topics, and he had the good fortune to see the total eclipses of 1900 and 1906. He married in 1886, and is survived by one son and one daughter.

He was elected a Fellow of the Society on 1901 June 14.

WILLIAM J. O'LEARY was born at Dublin on 1869 March 19, a son of Dr. W. H. O'Leary, M.P., a leading surgeon, Professor of Anatomy in the Royal College of Surgeons, Dublin, member of the Irish Party in the House of Commons and, remarkably enough, a friend of both Gladstone and Disraeli. He was educated at Tullabeg and Clongowes Wood Colleges and entered the Jesuit Order in 1886. He showed a marked capacity for scientific work and, as a young man at Louvain, received a solid foundation in mathematics, physics and astronomy. He spent many years teaching mathematics and physics in colleges in Ireland. He was a very successful and stimulating teacher, and his gift of lucid exposition is well shown in a textbook on Mechanics published in 1900.

His mind ran on original lines. He was never content with stereotyped textbook solutions; he had to work out each problem for himself from first principles. In this way he was able to study many questions from a fresh angle and to develop original lines of research in various branches of science.

Combined with this was a highly developed inventive talent and the ability to design new instruments and the skill to construct them.

In 1909 he set up a finely equipped meteorological and seismological observatory at Mungret College, Limerick. At the request of a Joint Committee of the British Association and the Royal Meteorological Society he carried out from 1911 to 1914 a series of upper-air investigations by means of sounding balloons. These were the farthest west observations made in Europe. The results attracted considerable attention at meetings of these Societies and were published by them.

One of the main problems in seismometry is to obtain an instrument with a fairly long period and consequent high sensitivity. Father O'Leary provided a satisfactory solution with his two-component horizontal seismometer with trifilar suspension. Leading seismologists, such as Professor Milne and Prince Galitzin, had high praise for the neatness of the invention. He completed one of these instruments in Mungret in 1911. In 1915 he started a seismological observatory at Rathfarnham Castle, Dublin. The O'Leary seismograph there, constructed by himself, with a moving mass of $1\frac{1}{2}$ tons, has given excellent service ever since. At the British Association Meeting in 1913 he showed plans for a new type of seismograph, a three-component one with photographic recording. Sir Howard Grubb, then of Dublin, arranged to construct this instrument, but the outbreak of war prevented a start being made; the firm was fully occupied with war-work, and the seismograph was never built.

The need for accurate timing in seismology turned Father O'Leary's attention to chronometry. As usual he went to the root of the problem. He soon saw that the secret of precision timing was to be sought in a free pendulum. He was, indeed, one of the pioneers in the development of the free-pendulum clock. A clock, patented by him in 1918, shows a definite advance in the method of synchronising the slave clock and the free pendulum by introducing a positive error in the slave clock (so that it always ran a little fast) and wiping it out every half-minute. Father O'Leary did not consider this an ideal arrangement and set to work to improve on it. In his later models it is immaterial whether the slave goes fast or slow, and correction is made, not every half-minute, but only when the slave is fast or slow. A clock of this type, beautifully made by him, has given good service at Riverview Observatory. Apart from various patent specifications no description of the clock has yet been published.

In 1929 Father O'Leary came to Australia as Director of Riverview College Observatory in succession to Father E. F. Pigot, S.J. Besides introducing various improvements in the seismological department (he promoted, for example, the more rapid interchange of results between the various Pacific stations), he initiated a programme of photographic research on variable stars in collaboration with the Bosscha Observatory, Lembang. Though he commenced this work so late in life, he developed new methods and devised new instruments. He invented and built a blink comparator which has proved very successful in searching for new variable stars. A few days before he died he completed a comparator of another new design. He

discovered many new variable stars and published several papers on variables in the *Publications* of the Riverview and Lembang Observatories and in the *Astronomische Nachrichten.*

Among various other inventions may be mentioned a recording anemometer and a petrol gas-plant. He was always most generous in handing on to others his ideas and unpublished work; for instance, more than one standard type of seismograph owes something to his inventive brain.

Father O'Leary was a most attractive speaker. His lectures on astronomy and seismology were greatly appreciated both by scientists and by the general public. His light and humorous touch combined with his clarity of exposition to render even abstruse topics intelligible and interesting. With all these activities he still found time to do much good work as a priest. Many people in various parts of the world will be grateful to him as an instructor and a wise counsellor. A wide circle of friends mourn the passing of a very attractive character.

Death came suddenly on 1939 April 16 from a heart attack. He knew of this weakness, and faced the prospect of a sudden death with perfect equanimity and cheerfulness, though he was so active that his friends hoped that he would be spared for many years. He retained his freshness of mind and originality until the end. Death interrupted plans for fresh researches in astronomy and seismology and for new instruments—a new type of vertical seismometer, a projection comparator, further improvements in his free-pendulum clock. The day before he died he discovered a number of new variable stars with his newly completed comparator, and that night worked at the telescope taking star photographs.

He was a member of the Royal Irish Academy, the Royal Society of N.S.W., the Société Astronomique de France, the Seismological Society of America, Past President of the N.S.W. Branch of the British Astronomical Association, and member of the Australian National Committee on Astronomy.

He was elected a Fellow of the Society on 1938 January 14.

MONTAGU AUSTIN PHILLIPS was born at Hampstead on 1879 November 14. He was educated at King's College, London, and was elected a Fellow of the Society on 1905 April 14.

Astronomy was only one of the many sciences of which Montagu Phillips was a keen student all his life, and he was a Fellow of the Linnean, Zoological, Geological, Geographical and Royal Entomological Societies, as well as being a member of the British Ornithologists' Union. His chief interest, however, was in Natural History, and in time he became one of the best-known lecturers in this subject. He deputised for the official guide-lecturer at the Natural History Museum for many years, and remained as an auxiliary lecturer there until a few months before his death. Besides his regular duties at the Museum, he travelled all over the country, lecturing and demonstrating. His knowledge of out-of-the-way subjects greatly increased the attractiveness of his lectures. At the close of 1938 ill-health compelled him to relinquish his work, and he died on 1939 January 11. He was unmarried.

HERBERT GEORGE ROBINS was born at Margate in 1867. In 1893, after some years in Australia, he went to Southern Rhodesia (before it was so named), close behind the pioneers of the Colony. In 1903 he went prospecting in the Belgian Congo, and discovered and mapped the tin belt there. He also did bacteriological work as inspector of sleeping sickness. Later, he returned to Southern Rhodesia and bought two farms, where he settled down to the business of running and extending a large private zoological park. For many years he fought continuously for the preservation of African wild life; his idea was to persuade the Government to establish a huge national game park from Ngamo to the Zambesi.

Mr. Robins studied many sciences as a hobby, and was elected a Fellow of the Society on 1913 July 12. With his long white beard, and the nightcap which he habitually wore, his appearance was that of a mediæval sage. He died on 1939 July 31, bequeathing his game reserve of 26,000 acres to the Government of Southern Rhodesia "to be held in trust as a sanctuary for wild game."

RALPH ALLEN SAMPSON was born at Skull, County Cork, on 1866 June 25. He was the fourth of the five children of James Sampson, a Cornishman, who was a metallurgical chemist by profession. When Ralph was five the family moved to Liverpool, and were subsequently impoverished by the combination of the illness of the father and the failure of the Cornish tin-mine industry in which Mr. Sampson's capital was invested. As a result of these straitened circumstances the son Ralph had very little education until he was fourteen, but it then became possible to send him to the Liverpool Institute and his ability soon made up for his earlier lack of opportunity. He eventually entered St. John's College, Cambridge, as a sizar, became a scholar of the College and graduated as third wrangler in the Mathematical Tripos of 1888. In the following year he gained the first Smith's Prize and was elected a Fellow of St. John's. At this time Sampson held a Lectureship in Mathematics at King's College, London, and was engaged in hydrodynamical research.

In 1890 an important academical event took place at Cambridge for which many students of astronomy have since had cause to be very thankful. This was the foundation, as a result of the munificent generosity of Mr. Frank McClean, of the Isaac Newton Studentship in Astronomy and Physical Optics. Sampson was the first holder of this Studentship, being elected in 1891. He accordingly returned to Cambridge and worked in astronomical spectroscopy with H. F. Newall, and the result of his activities was seen in 1893 when he published a paper of 62 pages in the *Memoirs* of the Society entitled, "On the Rotation and Mechanical State of the Sun." In the preface to this paper he wrote: "After proceeding a certain way with the theory of the Sun's rotation, it became evident that no conclusion could be reached without a satisfactory theory of the distribution of his internal temperature. With the existing theory of convective equilibrium I felt dissatisfied; accordingly I attempted the discussion of the distribution of

temperature by radiation and absorption and arrived at a theory which is explained in Part I, Section 3."

Throughout his career Sampson showed himself to be essentially a pioneer, and like other pioneers he often initiated lines of study which were destined to be followed up and worked out by others. It is interesting to notice that his pioneering instinct was manifesting itself in these early days, and that it led him to advance the hypothesis of radiative equilibrium in a star's interior, a hypothesis which has since dominated the theory of the interior of a star. It is also interesting to contrast Sampson's earliest astronomical research with the considerations which probably influenced his decision to leave London and return to Cambridge as an Isaac Newton student. In his undergraduate days he had been a pupil of J. C. Adams, and his interest in astronomy was stimulated by this association. But Adams was primarily a dynamical astronomer, and one of the most important of Sampson's researches, the theory of Jupiter's satellites, was destined to be in the field of dynamical astronomy. But it was not in this field, but in the field of astrophysics, that his first research work was conducted, and it was to astrophysical research that Sampson turned at a later stage in his career when his heavy labours on Jupiter's satellites had been completed. Dynamical astronomy aroused the patient scholar in him, but astrophysics set the pioneer in action, and as we shall see presently, his later astrophysical activities were again noteworthy as being the first step into unoccupied territory.

In the autumn of 1893 Sampson was elected to the Chair of Mathematics in the Durham College of Science at Newcastle-on-Tyne, and in 1895 he removed to Durham itself as Professor of Mathematics at the University. He interested himself in the Durham Observatory, where he was responsible for the erection of the Durham Almucantar, a fundamental instrument of attractive principle, and it was at Durham that the work was commenced which eventually led to the award of the Society's Gold Medal in 1928.

The theory of the Four Great Satellites of Jupiter had engaged the attention of the great dynamical astronomers of the nineteenth century. It is a particularly fascinating subject on account of the relation between the mean motions of Satellites I, II and III. But the state of the theory in which it was left by Delambre was disappointing in view of the large residuals which remained after comparison with observations of the eclipses of the satellites. Part of the trouble was felt to be due to the rather unsatisfactory nature of the observations of disappearance and reappearance at eclipse, and Sampson felt that the advent of the Harvard photometric eclipse observations warranted a re-examination of the whole question. He began with a careful discussion of the eclipse observations themselves, which was published in *Harvard Annals*, **52**, and incidentally he considered that the peculiarities of many of the light-curves gave evidence of the existence of an atmosphere to Jupiter, a conclusion which has since been verified by other evidence. From this work Sampson deduced a new set of elements by comparison with a theory which was based on Souillart's development of Damoiseau's work. But when the individual observations were compared

with this theory, using the new elements, the remaining discrepancies proved to be substantial in many cases, and Sampson was of the opinion that the observations could not be blamed. It was also clear that the discrepancies could not be removed by an attempt to develop the existing theory further, and with characteristic patience he set to work out the theory afresh. This work was completed by the time he left Durham, and the tables based on the theory were published by the University of Durham in 1910 under the title, *Tables of the Four Great Satellites of Jupiter*. These are the tables which have since formed the basis for computing the phenomena for the National Ephemerides. It was not, however, until 1921 that the new theory itself was published in vol. lxiii of the Society's *Memoirs*. In the course of revision subsequent to the publication of the *Tables* a few omissions were found, and they are tabulated in the last chapter of the memoir.

But in spite of the refinements introduced by the new theory, substantial residuals still remained when comparison was made with observation. De Sitter, who subsequently completed a further theoretical development, found that, contrary to expectation, the photometric observations are affected by systematic errors of the same order of magnitude as those found in ordinary observations of the first and last speck of light. This being so, it is now seen to be inadvisable to derive elements from eclipse observations alone, which are apparently subject to errors which may be as large as 10^s, and De Sitter's work is based on other available observations, including the measurements made with the Cape heliometer. But Sampson's research remains as a necessary stage in our efforts to obtain a really satisfactory theory of Jupiter's Galilean Satellites, which, on account of the smallness of their periods of revolution, are of special importance for the study of secular and long periodic perturbations in addition to the interest introduced by the commensurability of the mean motions of the three inner ones.

During his Durham days Sampson had undertaken and performed a task which was very much after his own heart. The Cambridge University Press was publishing the collected works of J. C. Adams, who had been Sampson's tutor. The first volume comprising all the published papers appeared in 1896, but there remained many papers on various branches of astronomy which were left in an incomplete state among Adams' manuscripts. The papers were practically devoid of arrangement; they were folded in parcels of a few pages each, and although the contents of the individual parcels were generally very clear in themselves, they carried no indication of their purposes or their relations to each other. Fortunately all the pages were dated and this permitted reference to a diary, but none the less the task of editing, which had been undertaken by Sampson, was almost herculean. However, he carried through with this difficult work, and the papers finally were published in 1900 as Part I of the second volume (Part II contained Adams' researches on Terrestrial Magnetism). The portion giving Adams' Lectures on the Lunar Theory was reprinted as a separate book, and in addition Sampson wrote a description (published in vol. liv of the Society's *Memoirs*) of Adams' manuscripts on the Perturbations of Uranus, with special reference to the 1843 manuscript containing his

first solution of the problem, which was reproduced in facsimile in Sampson's memoir. Sampson's scholarly mind and great patience made him peculiarly fitted to undertake this kind of work, and in 1904 he was asked to undertake the task of editor-in-chief of a complete edition of Newton's scientific works and correspondence. He would doubtless have carried out this enterprise with conspicuous success, but unfortunately the scheme fell through. Sampson had prepared a memorandum setting forth the outline of the proposed edition, and in 1924, stimulated by J. L. E. Dreyer's Presidential Address "On the Desirability of Publication of Isaac Newton's Collected Works," delivered at the Annual Meeting of the Society in that year, he wrote a note entitled "On Editing Newton," which included the original memorandum together with some general remarks on Dreyer's proposal. This note was published in the *Monthly Notices* for March 1924.

In December 1910 Sampson was appointed Astronomer Royal for Scotland, and Professor of Astronomy in the University of Edinburgh in succession to F. W. Dyson. At that time the Royal Observatory, Edinburgh, had just completed a meridian catalogue of zodiacal stars, and was busily engaged in the measurement of the plates for three zones of the Perth (Western Australia) section of the *Astrographic Catalogue.* It fell to Sampson's lot to supervise the completion of this work, but as a result of very unfortunate circumstances the measures have not yet been published. During the first part of his regime double-star work and spectroscopic observations of the Sun were continued. By 1914 we find his Annual Report laying great stress on all matters connected with the determination of Time, and right up to the end of his career his interest in this branch of astronomy never flagged. He also maintained his earlier interest in optical problems, and a paper by him entitled "On a Cassegrain Reflector with Corrected Field" was published in 1913 in the *Philosophical Transactions.* A further paper "On Correcting the Field of a Newtonian Telescope" was published in the *Monthly Notices* for May in the same year. In this, as in other matters, Sampson was ahead of his time, but it should be placed on record that at this period he realised quite clearly the desirability and the possibility of correcting the fields of reflectors. And, as happened in other fields of activity, his suggestions were eventually destined to be followed up by others.

But to return to Sampson's interest in matters appertaining to Time. In spite of the curtailment of work occasioned by the war of 1914 to 1918, we see from his Annual Reports how he was pushing on with work of this kind. We now pass on to the post-war period, and in the Report for the year ending 1922 March 31 we find mention of "a valuable clock which has been lent to the observatory by Mr. W. H. Shortt, who devised and constructed it." This clock was the forerunner of the famous Shortt free pendulum clocks, and it is largely due to Sampson's co-operation in testing this type of clock that it has now become part of the standard equipment of so many observatories. The original model was subsequently presented to the observatory and is now known as Shortt No. 0. Another free pendulum clock, Shortt No. 4, was installed in January 1925, by which

time other observatories were already reaping the reward of Sampson's foresight and enterprise and were installing free pendulum clocks. Some years previously Sampson had published an important paper on clock errors and wireless time signals (*M.N.*, **81**, 1, 1920), in which he called attention to the serious discrepancies between time observations at different observatories. There can be no doubt that this paper greatly stimulated the interest of astronomers in the problem of time determination. As a result of the attention which has consequently been lavished on the problem, and of the appearance of the free pendulum type of clock, the discordances have now been greatly reduced.

A very striking example of Sampson's pioneering instinct is to be found in the work carried out at Edinburgh on the distribution of energy in the continuous spectra of stars. Sampson was interested in photometric research, and during the war years of 1914 to 1918 he instructed E. A. Baker to embark on photo-electric experiments. At this time the idea was to fit a cell on a telescope and obtain direct readings of stellar magnitudes (as has in fact been done by other workers), but the aim of the research changed and the result was the construction of a photo-electric photometer of the Koch type designed to measure the densities of star images on photographic plates. Then came the idea of applying the instrument to the measurement of images of stellar spectra. More research by Baker followed on the intensity-density relationship of photographic emulsions, and finally a spectrophotometric programme was commenced which yielded what have since become known as colour temperatures of stars, although Sampson used the term "effective temperature," which is now reserved to denote a different concept. The stress was now laid on the methods of photographic spectrophotometry as worked out by Sampson and Baker, and the photo-electric photometer took its place as an accessory instrument for measuring the densities of the spectra. The methods employed have since been copied and extended by other workers, who have found it necessary to calibrate each individual plate instead of using a single reduction curve for a whole batch as was done by Sampson. The results of the work appeared in two papers published in the *Monthly Notices* for January 1925 and May 1930, and it was in the first of these papers that Sampson introduced the conception of spectrophotometric gradient, which has now become commonplace in astrophysical literature. Sampson's gradients were all measured relatively to the star Polaris, and the whole system of gradients were reduced to colour temperatures by assuming a temperature for Capella. His papers show how valuable information can be obtained by the determination of relative gradients alone without the comparison with laboratory standards necessary to derive colour temperatures. Perhaps Sampson himself did not fully realise this, but his work was certainly responsible for stimulating others to concentrate on the measurement of relative gradients. Modifications in Sampson's original pioneer scheme were only to be expected, and it is now the custom to measure gradients relatively to the mean of a selection of Ao stars, thereby making them analogous with colour indices. But this and other subsequent modifications and improvements do not alter the fact that other workers in

this field were inspired by Sampson's researches, and they know that their work is the logical continuation of the lead given at Edinburgh.

In the Edinburgh colour-temperature work the spectra were photographed with a 6-inch photo-visual to which an objective prism was attached. The exposures were necessarily long, and the programme was limited to stars brighter than the third magnitude. It had been obvious for some time that the observatory required extensive re-equipment, and in 1927 Sampson was able to announce that plans had been sanctioned for the erection of a 36-inch reflecting telescope and the acquisition of a new camera employing a 10-inch triplet lens. Provision was also made for a modern spectrograph to be attached to the 36-inch reflector and for other accessories. The new equipment was finally completed and installed in 1932.

Sampson's active career was now approaching its close. He continued in the direction of the observatory until 1937, when failing health hastened his retirement. For some months he travelled abroad, but eventually settled in the south of England, and on 1939 November 7 he died at Bath, being survived by his widow, a son and four daughters. He had been elected a Fellow of the Society in February 1892, and had been its President over the period 1915–17 and Vice-President for the two following years. In addition he served on the Council in the year 1909–10 and again from 1913 to 1915. He had been elected a Fellow of the Royal Society in 1903.

One of his most striking characteristics was his tremendous capacity for work. Mention has been made of his pioneering adventures, and it naturally happened that on occasions he embarked on a line of research which eventually proved fruitless; but his patience and persistence were wellnigh inexhaustible, and he would continue work in a particular direction long after a point had been reached at which other investigators would have given up the struggle. Beneath a superficially austere appearance he managed to conceal an essential geniality and a capacity for enjoying life. It cannot truly be said that he suffered fools gladly, he was no respecter of persons, and he judged others on a standard which was based on his own capacity for work. But to those who, in his eyes, came up to his requirements, he was essentially a helpful friend and colleague.

W. M. H. GREAVES

MARTIN CHARLES SHARP, a well-known journalist, died at Bournemouth on 1939 October 2 at the advanced age of eighty-five. He was born at Brompton on 1854 May 23, and received his early education at Highgate School; from there he went up to Trinity College, Oxford, where he read Jurisprudence. After graduation he was called to the Bar at Lincoln's Inn, but soon forsook his indicated profession for that of journalism. He was on the staff of the *Guardian* newspaper for over sixty years.

He was an enthusiastic amateur astronomer, but his profession prevented him from devoting as much time to it as he would have liked to do; however,

he possessed a small telescope and specialised on observations of variable stars, being particularly interested in stars of the Algol type. Although not having the opportunity for acquiring deep scientific knowledge, he always studied *Monthly Notices* with great interest, even though much of the contents seemed far away from the astronomy that he could indulge in. He was elected a Fellow of the Society on 1892 June 10.

He was an enthusiastic chess player and a keen shot, and competed at Bisley for many years; during the Great War he served with the Inns of Court Rifle Regiment. He married Harriett Louisa Oakeshott, by whom he is survived.

HENRY HAYDEN WATERS, of Rivermead, Durham Road, Harrow, Middlesex, was born at Coventry in December 1880 and died on 1939 September 14. His business activities were in the timber trade, and since a year or two before the Great War he had been associated with the firm of Vincent Murphy & Co., originally in Liverpool and more recently in London. From his father he inherited a deep and abiding interest in astronomy, and throughout his life this was his main hobby. He became a member of the Liverpool Astronomical Society in early manhood and served for a time as its secretary. In 1908 he joined the British Astronomical Association and was for some years a member of the Council. In the latter part of the 1914–18 war period he spent some time in the United States and visited Japan, Manchuria and Eastern Siberia. He took advantage of his stay in America to visit several of the larger observatories. Waters had a well-equipped observatory at his home in Harrow, the principal instrument being a fine 5-inch Zeiss clock-driven refractor belonging to the British Astronomical Association. This was housed in a spacious dome, and though, like all dwellers in the neighbourhood of London, he was increasingly incommoded by the constant extension of street-lighting and chimney smoke, he, and the friends who were glad to have the privilege of observing with him, were able to obtain many excellent views of the Moon, Mars, Jupiter and Saturn. But the branch of observation to which Waters gave most of his attention was the photography of meteors and the improvement of methods of recording and timing their trails. He presented several papers on this subject at meetings of the British Astronomical Association, and was an active member of the Meteor and Photographic Sections of that body. In 1921 he published a very useful and informative little book entitled *Astronomical Photography for Amateurs*.

For the last eighteen months of his life he was to a large extent incapacitated by a painful illness, but even then he occupied himself with mechanical and electrical experiments connected with this work, and towards the end with observations of time, temperature and barometric pressure from which he hoped to be able to isolate and determine the effects of temperature and pressure variations on the performance of his synchronome free-pendulum clock. Some years earlier he devised an effective equatorially mounted automatic meteor camera with which six plates could be exposed in sequence

in a run of six hours. Although he had not had the advantages of an engineering workshop training he had a natural ability which enabled him to make effective use of bits and pieces of material, that had originally served quite different purposes, in the construction of apparatus having real practical value. He represented the type of amateur to which science owes a great deal, and the ranks of the non-professional astronomers are much the poorer for his loss. Those who had the privilege and pleasure of knowing him intimately have lost a friend of rare quality. He leaves a widow and one son, from both of whom he received sympathetic encouragement in his astronomical pursuits.

He was elected a Fellow of the Society on 1919 January 11.

G. H. LEPPER

JACOB WERNER was the son of the late Rabbi Abba Werner of London, a revered minister of the Jewish faith. He emigrated with his family to South Africa in 1887, while still in his youth, first settling at Vryheid and later moving to Piet Retief, where he lived until his death on 1939 September 16. He soon became a prominent citizen of this small town and was Mayor for several years ; he was the proprietor of the principal hotel, which is renowned for its homely atmosphere. "Oom Jakob", as he was affectionately called by most people in his district, was a lovable character, combining energy and enthusiasm for all good works with boy sh simplicity ; he retained these qualities to the end, and although seventy-four at the time of his death, one could scarcely think of him as an old man. Werner was a prominent Freemason, and by his death "the Craft has been deprived of one whose every action was influenced by the principles it professes." He was largely instrumental in founding the Lodge at Piet Retief, and took a not inconsiderable part in the amalgamation of the two Masonic journals in South Africa. Astronomy was his hobby, and his lack of equipment was compensated by his enthusiasm ; he wrote many articles on sundials. He was the official meteorologist for the district and was childishly proud of the instruments in his hotel grounds. His wife, Rebecca Abrahams, whom he married in 1891, predeceased him, but he is survived by four children, his eldest son carrying on the hotel business.

He was elected a Fellow of the Society on 1930 January 10.

PROCEEDINGS OF OBSERVATORIES

The following reports of the proceedings of observatories during the past year have been received from the respective Directors, who are alone responsible for them.

Royal Observatory, Greenwich
(*Director, Dr. H. Spencer Jones, F.R.S., Astronomer Royal*)

Airy Transit-Circle.—The restricted programme of observations commenced in May 1938 is being continued. It comprises observations of the Sun, Moon and major and minor planets, together with appropriate clock and azimuth stars.

Meridian declination observations of the Sun made at Greenwich since 1750 form one of the principal items of evidence incorporated in a paper by the Astronomer Royal on the change in the rate of the Earth's rotation ; this paper was published in the *Monthly Notices* for May.

The total number of transits observed during the year was 1794, including 92 of the Sun and 77 of the Moon.

Reversible Transit-Circle.—The programme begun in the late autumn of 1937 is still in progress. Coupled with this work are the special observations of collimation and level taken concurrently with transits of stars.

The louvred screens fitted to the outside of the collimator houses have assisted in improving the definition generally. Difficulty, however, still exists when temperature changes are rapid.

Investigations into the diurnal changes of collimation and level in relation to temperature changes in the telescope and piers are still proceeding. Extensive data are required before definite decisions on these important instrumental errors can be made.

In order to reduce as much as possible the diurnal fluctuations of level, the exposed metal of both piers was covered with felt at the end of November.

Work on the division errors of the fixed circle is still proceeding steadily, whenever possible. The amount of work involved is large, as the errors are determined over an arc of 120°.

Cookson Floating Zenith Telescope.—During the year, 235 plates were taken for the determination of the variation of latitude, and 2 plates for the determination of scale. The latitude variation for 1936–38 has been published in *Monthly Notices*, January 1939, together with a comparison of the Boss G.C. system of declinations with declinations obtained from the Cookson results. A discussion of the distribution of the residuals of the measurements is also given in the same volume (June).

28-inch Refractor.—A further fracture of the dome rail, in April 1939, restricted the possibilities of observation. The question of fitting new wheels was considered, since their chipping has undoubtedly contributed to the fractures. Meanwhile observations were chosen so as to require little

or no rotation of the dome; this naturally restricted the programme, but it was usually possible to find some star that could with profit be observed. At the beginning of September the object-glass was dismounted as an emergency measure, and observational work is now in abeyance.

179 measures of double stars were obtained, distributed as follows :—

Separation	...	> 2″·0	2″·0–1″·0	1″·0–0″·5	< 0·5
No. of Obs.	...	17	42	79	41

Thompson Equatorial.—783 plates were taken for the determination of parallax up to the beginning of September, when the object-glass was dismounted. 1396 plates were measured and 47 parallaxes were completed. The parallaxes of 42 stars were published in the *Monthly Notices* for November. 32 plates were taken for the determination of proper motion.

Yapp 36-inch Reflector.—The measurements and reductions for the colour temperature work have all been completed, and a volume containing the results, together with experimental details and a discussion, was dispatched for printing in July. Owing to the war its appearance has been postponed, and it is planned to publish some parts, including all the final data, in the *Monthly Notices*.

The Yapp telescope drive is not satisfactory unless there is an appreciable positive load on it, such as can be obtained, for a limited number of positions, by having the telescope permanently out of balance. Owing to the great freedom of the bearings, however, it is undesirable to have the instrument appreciably out of balance when unclamped. A weight has accordingly been fitted to the arc; since the arc is a complete circle, the weight is arranged to pull on any one of eight studs. A warning bell indicates when the top of its travel is reached, and it is easily changed to the next stud without interrupting the exposure or using a light.

The declination setting and guiding motor failed in 1938, and the replacement failed shortly afterwards. During the intervals, an improvised hand guiding was fitted which proved satisfactory except for its inaccessibility. A system of additional controls linked by a bicycle chain was accordingly outlined to Messrs. Grubb, Parsons, who generously undertook to design and make the necessary parts without cost if the observatory would undertake to fit them. They have now been in use for some time; at least one control is easily within reach from the guiding telescope at all orientations of the spectrograph, and the motion is both rapid enough and sensitive enough for all requirements. In practice it is actually more convenient than the electrical control, as the mercury switches allowed an uncertain amount of over-run.

The hyperboloid Cassegrain has been aluminised, with the expected improvement in ultra-violet efficiency. It is not, however, proposed to aluminise the main mirror yet. Smaller aluminised mirrors directed upwards have been found to have a life, under Greenwich conditions, of not more than a year, and the delay and expense involved in recoating would be considerable with the 36-inch.

The slit spectrograph was out of action for a time early in the year on account of failure of the circulating fan in the case. The fan motor has now been mounted outside the case; it is clear, however, that it is not of a really suitable type, and the fan has, in fact, little effect. A number of adjustments to the slit assembly have been made.

Tests have shown that while the transparency and flatness of field in the spectrograph are quite satisfactory, the definition, especially with the single-prism arrangement, is very appreciably disturbed by coma and allied aberrations.

The spectrograph has been employed on a tentative programme; one-prism spectra, exposed for the far ultra-violet, are being obtained for all yellow giant spectroscopic binaries, accessible with a few hours' exposure, for which the secondary spectrum has not yet been observed, and also of yellow and blue comparison stars. It is proposed to study the micro-photometer tracings for indications of a possible hot companion to the main component in the binaries, since such a star might show up in the ultra-violet even if its lines were undetectable at the wave-lengths used to establish the binary characters. So far 71 spectra of 53 stars have been obtained, with intensities that are adequate as far as about λ 3400.

The microphotometer mentioned in last year's report has been installed and subjected to a number of tests. It was found that the galvanometer was disturbed by vibration of the building, especially on windy days; this has been almost entirely eliminated by the use of a platform with damped spring suspensions. The total inertia of thermopile and galvanometer is enough to cause some distortion of the trace at all speeds except the slowest, but the distortion is only slight at a speed that is fast enough for all practical purposes. The accuracy of the screw is not altogether satisfactory.

In other respects the instrument comes up to expectations, and it is being taken into regular use.

Astrographic Equatorial.—The instrument was dismantled in March, and the tube, lens and breech-piece of the 13-inch photographic telescope were sent to Messrs. Grubb, Parsons for fitting to the eclipse equatorial mounting. These parts have now been returned, and will probably be re-erected before long.

Observations of Eros.—16 plates of Eros taken with the astrographic telescope between 1935 October 4 and November 13, and 46 plates taken between 1937 November 25 and 1938 February 25, have been measured.

A series of plates covering the path of the planet during the above-mentioned oppositions has been received from Hamburg (Bergedorf) Observatory through the courtesy of Dr. Schorr. These plates will serve to determine the places of the reference stars required for the reduction of the Eros photographs, the positions of these stars being based on those of the A.G. stars shown on the plates.

The collection and reduction of observations made near the opposition of February 1931 are proceeding. The tabular places of the planet for the series of visual observations made at Berlin (Babelsberg), Poulkovo, Heidel-

berg, Besançon and La Plata have been computed and compared with the published positions which have been corrected to the system of final star places.

During the year, the results of observations made at the following observatories have been received :—

Cape (13-inch astrographic)	529 plates
Van Vleck	121 ,,
Dearborn	212 ,,
Cordoba	277 ,,
Leander McCormick	34 ,,

These results are being incorporated with those previously reported.

The results of most of the observations of Eros at the favourable opposition have now been received from the co-operating observatories and most of the results still outstanding have been promised in the near future. The discussion of the observations for the derivation of the solar parallax and the mass of the Moon has been commenced.

Three plates of the planet Pluto taken 1936 March 18, 21 and 24 have been measured and reduced.

Photoheliograph.—The Sun was photographed on 285 days at Greenwich. Up to October 31 no day is unrepresented in the combined series to be selected for measurement from the Greenwich, Cape and Kodaikanal plates. The measurement of the 1938 series has been nearly completed. Sunspot frequency has been high generally throughout 1939, although the decline towards minimum has now definitely set in after the unusually high maximum in 1937–38.

Spectrohelioscope.—Observations were made of the Sun's disk in $H\alpha$ on 170 days ; on 44 of these days observations could be made only for a few minutes. The observations included, as in previous years, (1) radial velocity measures, (2) bright chromospheric eruptions and (3) photometric measures. On May 9 at $15\frac{1}{2}^{h}$ five measures of radial velocity were made (before cloud intervened) on an eruptive absorption marking associated with a bright eruption. The measured velocities ranged progressively from -200 km./sec. to $+85$ km./sec. If depicted on a moving film, run through the projector at the normal rate at which recent prominence films have been shown, these extreme velocities would have been seen within $1\frac{1}{2}$ seconds.

A statistical study of bright eruptions, sunspots and magnetic storms has been made during the year, and the results described in the *Observatory* for December 1939.

Photometric work was chiefly devoted to the use of a simple direct-wedge photometer thrown into a specific form for the general observation of bright eruptions with the spectrohelioscope. A description of the instrument is given in *M.N.*, **99**, 463, 1939.

1940 Eclipse.—The Observatory expedition has been cancelled, but it is probable that some apparatus may be lent for an expedition from the Cape and Radcliffe Observatories. The 3-prism spectrograph is essentially

complete, though some wooden casing remains to be constructed. The field equatorial was sent from Messrs. Grubb, Parsons in a partially completed state, and has been erected in the workshop for rough balancing. Essentially, the refractor set-up is complete ; a clock drive is to be supplied shortly ; the reflector parts are not being made at present ; the spectrograph for the reflector, which is under construction at Cambridge, is, however, in an advanced stage and will be completed ; and the figuring of the two mirrors is also continuing.

Nautical Almanac Office.—The work of the Office has been devoted to the calculation of data for and the proof-reading of the *Nautical Almanac* for 1941 and subsequent years, the *Abridged Nautical Almanac* for 1941, the *Air Almanac* for the second half of 1939 and for 1940, the various volumes of *Astronomical Navigation Tables*, and the first volume of *Apparent Places of Fundamental Stars*, for the year 1941. In spite of the arrears of preparation overtaken in 1938, the two *Almanacs* for 1940 did not show such a substantial gain in date of publication as was anticipated in last year's report ; owing to difficulties of paper supply they were not published until March, 5 weeks only in advance of those for 1939. This year it has been possible to complete both *Almanacs* before the end of December, and it is hoped that publication will follow early in 1940. It is satisfactory to report, however, that the *Air Almanac*, which is issued quarterly, has been appearing consistently at intervals of 11 to 12 weeks, and that the arrears with which it was necessary to start this 180-page publication have now been completely overtaken.

The occultation programme has been continued without appreciable modification. For 1941, the programme of prediction was completed early in the year ; the 7999 approximate times, given by the occultation machine for subsequent computation, yielded 4816 separate predictions for 1165 stars and 4 planets and involved 8563 computations. The large number of approximate times that did not materialise in predictions is accounted for firstly by the policy of retaining all doubtful cases, and secondly by taking approximate times for stations for which accurate predictions are not made. In the course of the machine work for 1942, 2584 stars were examined ; of these 1376 have been retained, yielding 8433 times for subsequent computation. Reduction elements are computed in duplicate for all stars retained, and those for 1942 are now nearing completion. In 1942 it is hoped to give information to warn observers when the occulted star is double.

The second volume of Planetary Co-ordinates for the equinox of 1950·0, and the volume of 7-figure table of the four principal trigonometrical functions with argument in time, were published in September.

The volume of *Apparent Places of Fundamental Stars* for 1941, containing the mean and apparent places of the 1535 stars in the FK3, is well in hand, and the larger part is now in the proof stage. It is hoped that it will be possible to issue this volume shortly after the anticipated date (April 1940) in spite of present circumstances. The calculation of the apparent places is shared between France, Germany, Spain and the United States, and the

Office is responsible only for the necessary collation, checking, proof-reading and printing; advance computations for future years have already been received and there will therefore be no difficulty in continuing to issue subsequent volumes.

No major changes of content or presentation have been made to any of the routine publications that have appeared during the year. The *Nautical Almanac* for 1941 has, however, been considerably reduced in size by the restriction of the number of apparent places of stars to 208. Consequent on a change of printer, preparations are in hand for revision of the permanent tables and explanation of the *Nautical Almanac* for 1942; it is now doubtful, however, whether it will be possible to complete the full programme of revision given in the preface to the *Almanac* for 1941.

A supplement to the *Nautical Almanac* for 1940 was published, which extended data for the eclipse of 1940 October 1.

The *Air Almanac*, in the revised form introduced at the beginning of 1939, has met with appreciation, and it is gratifying to know that it is reproduced in facsimile (by arrangement) in the United States.

Four volumes of the *Astronomical Navigation Tables* have now been issued, four more are in various stages of being printed, and computation and copy have been commenced for two others.

In the later part of the year the Office has been supplying "black-out" times in response to numerous official and unofficial requests. Also, two supplements to the *Abridged Nautical Almanac* for 1939 and 1940 have been issued; these contain an extension of the data given in the *Almanac* for sunrise, sunset, twilight, moonrise and moonset to latitudes from 60° N. to 73° N. The supplement will be continued for 1941, and in 1942 will be incorporated as a permanent addition to the *Almanac*.

Time Service.—Observations of clock error were made on 126 nights. The transit observations and wireless time-signals were recorded against Shortt No. 3 from January 1 to July 31, and then against Shortt No. 11 until the end of the year. A "mean clock" as described in last year's report has been used throughout for determining final corrections.

A crystal clock has now been installed. Though a number of minor difficulties were experienced in the initial stages the clock is at present operating satisfactorily, though it has a rather large gaining rate.

The time-signal service has been maintained. Thermionic relay units have been designed to replace mechanical relays on all fundamental circuits, and are in process of installation. Since September all the recording apparatus has been moved and no cathode-ray oscillograph records for the determination of recorded lag have been obtained, but it is hoped to make arrangements for these early in the new year. Annapolis long-wave time-signal transmission recommenced on June 1 and corrections to the signals received here have been published. Since March the corrections to wireless time-signals have been distributed direct from Greenwich, the publication of the corrections in Admiralty Notices to Mariners being discontinued.

The short-wave receiver referred to in the previous report has been transferred to an emergency time station which is at present equipped

with two Dent clocks and a small transit instrument. Mr. R. H. Fry has generously loaned his clock, Shortt No. 61, and an additional wireless receiver, and has presented a chronograph to the observatory for the same purpose.

Printing.—The following publications are ready for limited distribution:—

Greenwich Observations, 1936 (complete volume and separate parts).

Observations made with the Cookson Floating Zenith Telescope in the years 1927–1936, and *The Determination of the Variation of Latitude, 1911–1936*.

Royal Observatory, Edinburgh
(*Director, Professor W. M. H. Greaves, Astronomer Royal for Scotland*)

The measurement of total intensities of lines in the spectra of stars of types O and B has been continued. Attention is being concentrated on the hydrogen lines $H\alpha$, $H\beta$ and $H\gamma$, the helium lines at 4472 A., 5876 A. and 6678 A., the ionized oxygen line at 4649 A., the ionized magnesium line at 4481 A. and the interstellar sodium lines D_1 and D_2. The spectra are photographed with the 36-inch reflector used in conjunction with the Hilger spectrograph in its two-prism form. The plates are calibrated with a multiple slit calibration spectrograph, and are measured with the microphotometer of the Moll pattern whose construction was reported last year. This machine was designed with a view to easy direct readings of the galvanometer deflection, although it is proposed to incorporate a self-recording attachment. The instrument has proved to be highly satisfactory.

The original driving clock of the reflector has been replaced by a drive incorporating a three-phase synchronous motor. The new drive was installed by Messrs. Sir Howard Grubb, Parsons & Co. and has given complete satisfaction.

The examination of the Kapteyn selected areas 2 to 19 for variable stars has been continued. The plates, which cover an area of 6 degrees square, are being taken with the 10-inch triplet Grubb lens of 60 inches focal length, and are examined with the blink comparator constructed some years ago in the observatory workshop. The blinking of the plates exposed on areas 2 to 8 inclusive is now complete, and the examination of the material has been completed for areas 2 to 7, comprising the fields distant 15° from the Pole. Nineteen new variables have been found in these fields and several other stars are suspected of variation. Areas 2 to 7 are non-galactic fields and the yield of new variables has been small, but the preliminary examination of area 8, which is a galactic area, shows that the work will reveal a large number of new variables in this area.

During the year the first number of the new *Publications of the Royal Observatory, Edinburgh*, was issued. It contains descriptions of the method employed in adjusting the objective of the 10-inch triplet lens, and of the construction of the blink comparator. The copy for press of the second number has been prepared, but its appearance has been postponed as a result of the war. It contains a description of the working methods

employed in the search for new variables, and sets forth in detail the results for areas 5 to 7. The results for areas 2 to 4 had been previously published in the *Monthly Notices*.

The Rugby signal at 10^h U.T. was received regularly, and its time of reception, as recorded by the free pendulum clock Shortt No. 4, forwarded to Greenwich. This enables this clock to be incorporated in the Greenwich "Mean Clock."

Spectra of the Sun, for the measurement of rotation, were secured on eight days.

Two occultations of stars by the Moon were observed by a volunteer worker, Mr. I. Storey.

The printing of the measures of the Perth Astrographic Plates for Zone $-40°$, 6^h to 24^h, has been commenced, and the copy for press for Zone $-39°$ has been finally checked. As was mentioned in last year's report, the printing is being financed by the International Astronomical Union, and a contract for the printing has been placed with Messrs. E. Privat of Toulouse. The copy for press for Zone $-40°$ was forwarded to the printers in July and, in spite of the difficulties arising from the war, the printing is proceeding. With a view to easing some of the difficulties Dr. J. Baillaud, President of Commission 23 (Carte du Ciel) of the International Astronomical Union, very kindly offered to supervise the reading of the first proofs against the manuscript. This generous offer was most gratefully accepted. The second proofs will be read at Edinburgh. Dr. Baillaud's kindness serves as an effective precaution against the possible loss of manuscript prior to the correction of the relevant section of the first proof.

The measurement of the Perth plates for Zones $-40°$, $-39°$ and $-38°$ was performed at Edinburgh during the years 1908 to 1915, but up to the present no publication has been possible apart from the measures for Zone $-40°$, 0^h to 6^h, which were published by the Perth Observatory in 1922. It is very satisfactory to be able to report that the printing has at last commenced.

Royal Observatory, Cape of Good Hope
(Director, Dr. J. Jackson, F.R.S., H.M. Astronomer)

Reversible Transit Circle.—The observation of the Boss and Backlund-Hough stars south of declination $+35°$ begun in 1936 was continued. During the year 12,330 transits were observed. These include observations of the Sun on 212 days, Mercury on 104 days and Venus on 147 days. The major planets were observed on about two nights a week, when they culminated in the evening hours, and the four large minor planets were similarly observed. Towards the end of the year the Moon was also observed at evening transits.

Meridian Reductions.—The copy for press of a catalogue of stars formed from observations made in the years 1925–32 was completed. This contains 8400 stars south of declination $-30°$ and 3267 zodiacal stars. The copy for press of another catalogue of 6597 stars between the equator and $-30°$,

observed in the years 1932–36, is well advanced. Both catalogues are for the equinox of 1925·0. Comparisons have been completed with the Albany General Catalogue and hourly means for zones 10° wide have been analysed. The following table gives for R.A. the differences Cape minus G.C. :—

Dec.	Constant	Coefficient of				No. of Stars
		cos α	sin α	cos 2α	sin 2α	
° °	s	s	s	s	s	
−70 to −80	−·0229	+·0472	−·0059	−·0174	−·0046	486
−60 ,, −70	+·0031	+ 363	− 98	+ 106	− 153	892
−50 ,, −60	+·0238	+ 184	− 110	+ 99	− 42	1515
−40 ,, −50	+·0185	+ 134	− 66	+ 65	− 11	2081
−30 ,, −40	+·0031	+ 117	− 103	+ 85	− 28	1499
−20 ,, −30	−·0068	+ 63	− 98	+ 93	− 27	1548
−10 ,, −20	−·0111	+ 87	− 129	+ 47	− 41	1139
0 ,, −10	+·0046	+ 112	− 138	− 9	− 16	1327

Periodic corrections had been applied to the Cape positions to allow for the error in the Boss system shown by comparison of day and night observations. This was done independently for the two catalogues as follows :—

Cape minus Boss

1925–1932. $-{}^{s}\cdot0460+{}^{s}\cdot0117\cos\alpha-{}^{s}\cdot0127\sin\alpha+{}^{s}\cdot0058\cos 2\alpha-{}^{s}\cdot0011\sin 2\alpha$
1932–1936. $-{}^{s}\cdot0460+{}^{s}\cdot0116\cos\alpha-{}^{s}\cdot0124\sin\alpha+{}^{s}\cdot0034\cos 2\alpha-{}^{s}\cdot0018\sin 2\alpha$

A similar analysis for the declination gives for Cape minus G.C. :

Dec.	Constant	Coefficient of			
		cos α	sin α	cos 2α	sin 2α
° °	″	″	″	″	″
−70 to −80	−·055	−·049	+·050	+·138	−·048
−60 ,, −70	+·058	−·113	+·018	+·127	+·022
−50 ,, −60	+·016	−·093	+·045	+·070	+·016
−40 ,, −50	+·003	−·102	+·018	+·072	−·004
−30 ,, −40	−·168	−·110	−·036	−·001	+·036
−20 ,, −30	−·117	−·062	−·134	−·022	+·028
−10 ,, −20	−·299	−·043	−·094	·000	+·018
0 ,, −10	−·235	−·119	−·104	−·044	+·033

The probable error of a single observation is $\pm$ s·023 in R.A. and $\pm$ ″·30 in dec. or for a catalogue place depending on four observations $\pm$ s·012, $\pm$ ″·15.

The proper motions of 537 stars south of −30° not in the G.C. have been determined. For 1869 stars between the equator and −30° the proper motions are being determined, and it is hoped to get the proper motions of 528 zodiacal stars from Washington to complete the catalogue.

The discussion of the observations of the Sun, Mercury and Venus made in the years 1925–36 was completed and the copy for press was prepared.

Eight-inch Transit Circle.—The observation of standard stars for the zone $-52°$ to $-56°$ was completed in January 1939. All the observations have been reduced to 1950·0 and are now available for the reduction of plates of this zone.

Photographic Zone Observations with the Wide Angle Lens—(a) *Zone* $-30°$ *to* $-35°$.—The reduction of the measures of 12,500 stars has been completed with the formation of places for 1950·0 and the determination of proper motions. The positions are on the FK3 system and have been compared with the G.C. The results are now ready for the preparation of copy for press.

(b) *Zone* $-35°$ *to* $-40°$.—The measurement of 12,000 stars in this zone has been completed by the measurement of the remaining 52 plates. The residuals of the 1680 standard stars have been analysed. The diameters of all stars in this zone were measured and a correction depending on magnitude has been found.

(c) *Zone* $-52°$ *to* $-56°$.—The plates for this zone were taken in 1938. About 6000 stars from the La Plata Catalogue (1925) will be measured, together with 3000 to 4000 stars selected from the C.P.D. and mostly in the Henry Draper Catalogue. The selection of stars has been completed to $3\frac{1}{2}$ hours of R.A. and the computation of standard co-ordinates has been commenced.

Victoria Telescope.—During the year 3375 plates were taken for parallax determinations, 2183 were measured and 86 rejected. There are now 5712 plates remaining for measurement. A list of 78 new parallax determinations was sent to the Society for publication, bringing the total since this programme was commenced in 1926 to 1000. A further 38 parallax determinations have been completed.

The proper motions in declination of 78 stars have been determined from plates taken at an interval of five or more years. These are stars for which a parallax has been determined. This work is in preparation for a part of the *Cape Annals* giving details of parallax determinations.

Photometric Lenses.—Work on the photometric programme outlined in the last annual report has continued steadily throughout the year. During 1939, 101 pairs of plates, photographic and photovisual, have been obtained of the zone $-30°$ to $-35°$, 9 pairs of the Harvard Standard E Regions and 15 pairs intercomparing the E Regions with themselves and with the zone regions. Seven pairs of plates have also been taken of the Pleiades, the Harvard Standard Regions at $-15°$, etc. The effective wave-lengths are about 4500 A. for the photographic and 5580 A. for the photovisual magnitudes. In addition, 8 pairs of plates for photometric purposes have been taken with the astrographic telescope and with the wide angle lens, the former being stopped down to 7 or 10 inches aperture. These plates were mainly of the E Regions.

Thirty-seven pairs of zone plates have been measured in 1939. Of the

plates of the E Regions 7 pairs have been measured, and 11 pairs measured in 1938 remeasured. Twenty-eight other plates, mainly those taken for special investigations or those obtained with the astrographic or the wide angle lens, have also been measured. About 10 additional stars with magnitudes between 7 and 8 have been measured in each of the E Regions to serve as subsidiary standards.

Remeasures of the same plate indicate that over the range of magnitude measured (about $3\frac{1}{2}$ magnitudes) the probable error of a single measure and reduction is about $0^{m}.016$, while the probable error of a single magnitude determination as found from comparison of different plates of the same region is about $0^{m}.05$.

Considerable time has been devoted to attempts to improve the Schilt photometer. The chief cause of trouble has been the instability of the thermopile-galvanometer system whenever there is a high wind blowing, which is, unfortunately, a very frequent occurrence at the Cape. No satisfactory solution has been found, but measurement is now only attempted on those days on which the wind is relatively quiet. After the present programme is finished it is proposed to replace the thermopile either by a photronic or by a photo-electric cell.

Another cause of trouble has been the lack of planeness of some of the photographic plates. The earlier plates were of ordinary glass. Plates on thick selected glass are now being used. Some of the worst of the earlier plates are being repeated.

Various methods of reduction have been tried. That at present being used is the separate solution for each plate of the difference equation defined by the difference in the galvanometer reading for the central and for the first diffracted image, the grating constant being assumed to be 2 magnitudes. The resulting solution is then corrected for scale and zero-point by means of a few stars of known magnitude. The method is rather a cumbersome one, but it is hoped that with an increased amount of data it will be possible to replace the individual solution by a number of standard ones such as the one employed at the Leiden Observatory.

One rather unexpected result that has come to light is the apparent variability of the grating constant. This variability seems to be related to the quality of the seeing, the grating interval being greater on nights of poor seeing and smaller on nights of good seeing. It also appears to vary slightly with the spectral type of the star, but as far as can yet be ascertained by an amount which is of no practical importance in the present programme.

Occultations.—As usual an attempt was made to observe all the occultations predicted in the *Nautical Almanac*. In all 48 observations of 32 phenomena were secured. The results of the observations for 1938 were published in the *Monthly Notices* and the reduction of the observations for 1939 is nearly complete.

Photoheliograph.—Two plates of the Sun were obtained on 345 days and one plate on another day, leaving only 19 days unrepresented, of which 6 were in August. Zero plates were taken fortnightly and zero visual observations were made weekly.

Publications.—The catalogue giving positions, photographic magnitudes, proper motions and spectral types of 20,554 faint stars in the zone $-40°$ to $-52°$ which was passed for press has not been issued. The printing of other catalogues has been suspended.

Armagh Observatory
(*Director, Dr. E. M. Lindsay*)

Star-counts between $m_{ptg.}$ 10 to 14 within the galactic belt $l = 290°$ to $l = 360°$ and $b = \pm 25°$ have now been completed. The counts have been reduced and are under discussion.

The old transit room has been converted into a display room containing photographic transparencies. The meridian circle room has been adapted to an astronomical museum containing the many valuable astronomical museum pieces of the observatory.

University lectures have been given on two days a week and practical instruction to the students at the observatory.

The meteorological work has been continued as usual. A full-time assistant is now available to take over some of the routine work of the observatory.

Cambridge Observatory
(*Director, Sir A. S. Eddington, O.M., F.R.S.*)

Staff.—Dr. Woolley resigned at the end of October, having been appointed Director of the Commonwealth Solar Observatory, Canberra. The post of Chief Assistant will be left vacant for the present. In the meantime, Dr. H. Brück, Assistant in the Solar Physics Observatory, occupies the house, and renders such assistance as is necessary.

Observations.—Up to September Mr. Green continued the programme of photo-electric observations for the purpose of testing the constancy of the light of the stars. The following sets of comparisons were obtained: type G stars, 30; extinction factor, 7. The object-glass and mirror of the Sheepshanks telescope were removed in September, but were remounted in order to observe the eclipse of ζ Aurigæ. A satisfactory magnitude-determination was obtained during ingress on December 19; the weather during egress was cloudy.

Dr. Woolley continued his measurements of double stars with the Northumberland and Thorrowgood telescopes. His collected measures during the period 1937 June to 1939 August have been published in *Monthly Notices*, **99**, 742.

The Thorrowgood telescope has been used by members of the Solar Physics Observatory for observation of occultations.

Photo-electric Research.—Dr. Woolley and Mr. J. R. F. Jeffreys continued their laboratory experiments in preparation for a determination of the Sun's apparent magnitude. Dr. Woolley has taken the equipment with him to Australia, where he hopes to carry on the investigation.

Steavenson Telescope.—In October 1938 an arrangement was entered into with Dr. W. H. Steavenson, who had acquired a new 30-inch reflector and wished to erect it in a location where it could be advantageously used by himself and others. His proposal to erect and house it in the grounds of the observatory, and to share its use with the observatory, was gladly accepted. The site chosen is in the paddock at the back of the main building. The erection of the dome and telescope has now been completed, but the instrument has not yet been brought into use.

Solar Physics Observatory, Cambridge University
(*Director, Professor F. J. M. Stratton*)

Solar Work.—Spectroheliograms of the disc in K_{232} light were obtained on 93 days, in $H\alpha$ on 85 days ; photographs of the limb on 13 and 67 days respectively. These observations were made on 104 days. On 3 days serial exposures were made at short intervals on areas shown to be active by the spectrohelioscope observations.

Visual observations with the spectrohelioscope were made on 156 days. The number of bright chromospheric eruptions observed was 43 ; of these, 2 were of class III, 5 of class II and 36 of class I.

The photo-electric recording photometer attached to the McClean solar spectrograph has been partially redesigned. In its present form (described in *M.N.*, **99**, 607) the instrument has proved to give very satisfactory results. A number of tracings of Fraunhofer lines near λ 4227 have been obtained.

Several investigations of sunspot numbers have been made and a note on the initial rate of growth of sunspots has been published (*Observatory*, **62**, 281).

Stellar Work.—226 spectrograms were obtained with the Newall 25-inch refractor on 93 nights (the telescope has been out of action since September 2). The programme on line-intensities in the visual region of K-type spectra has been continued and a paper on the change of *Mg* 5183 with surface gravity published (*M.N.*, **99**, 492). Special investigations of the spectra of δ Cep, β Lyr, α CVn, α CMa, α And, ρ Cas and o Leo have been made.

Spectra of ζ Aur were obtained with the Huggins refractor during the eclipse of the B component in December.

The probable errors of spectral types in the Mt. Wilson, Victoria and Henry Draper Catalogues are being studied.

Meteorological Physics.—A discussion of the results of ten years' observations has been published by the Royal Society : "The Effects of Thunderstorms and Lightning Discharges on the Earth's Electric Field" (*Phil. Trans.*, **238**, A, 249).

Further investigations are in progress on the net effect on the electric field of distant lightning discharges, using a capillary electrometer with a simple thermionic amplifier, and also on the fine-structure of the effects of discharges at various distances, using cathode-ray equipment.

Miscellaneous.—An atlas of the spectrum of Nova Herculis 1934, from λ 3600 to $H\alpha$, embodying enlargements of plates taken at 26 observatories,

has been published ; these include photographs taken on nearly every night from discovery (December 13) to the great fading (April 1935). The method of reducing the many dispersions (prismatic and grating) to the same scale has been described in *Observatory*, **62**, 73.

Since October a programme of observations of occultations has been begun, using the Thorrowgood telescope of the University Observatory (by permission of the Director). Laboratory tests of personal equation in the observation of expected and unexpected disappearances have been carried out in connection with this programme.

The 2-prism spectrograph used at the 1936 eclipse by Dr. Redman has been modified to include a third prism and two new lenses of 8 feet focal length, giving a sufficiently flat field for plates to be used.

Temperature control has been attached to the 1-prism spectrograph of the Huggins refractor.

A curious behaviour of certain photographic emulsions subjected to prolonged fixation has been studied.

Staff.—Mr. N. B. Slater joined the staff as Second Junior Observer on April 1. Dr. Redman, of the Radcliffe Observatory, Pretoria, left for South Africa in February. The following have also worked at the observatory during the year : Dr. G. A. Archenhold, Dr. A. Beer (since September), Mr. H. E. Butler, Dr. V. A. Goedicke of the Michigan University Observatory (January to June), Mr. J. R. F. Jeffreys (Isaac Newton Student), Mr. E. T. Pierce and Mr. W. S. Tai. Visitors to the observatory included Dr. Theodore Dunham, jun., M. B. Lyot and Miss A. V. Douglas.

University Observatory, Glasgow
(*Director, Professor W. M. Smart*)

The new observatory buildings were formally opened on April 17 by Sir Arthur Eddington, O.M., in the presence of a representative assembly presided over by the Chancellor of the University, Sir Daniel Stevenson, Bart., who was supported by the Principal, Sir Hector Hetherington, and Professor John Walton, Dean of the Faculty of Science. During the proceedings Sir Arthur Eddington gave an address on "The Expansion of the Universe."

The Director and Mr. Tannahill have continued their detailed study of the Cape photographic Proper Motions ; the solutions for star-streaming according to spectral type are well advanced. Preliminary work on the Proper Motions of the *General Catalogue* has made satisfactory progress, part of which is due to the assistance of Dr. R. A. Robb. The Director has continued his investigations on moving clusters and allied problems ; at the end of the year a paper on "The K Term and the Galactic Rotational Constants" was communicated to the Society.

Since October, Messrs. Akbar Ali, M.A., B.Sc., Archibald Brown, M.A., and P. C. Chaudhuri, M.Sc., have been working as research students on various problems of stellar kinematics.

The papers published during the year include: "The Moving Cluster in Taurus," by W. M. Smart (*M.N.*, **99**, 167); "The Ursa Major Cluster" (two papers), by W. M. Smart (*M.N.*, **99**, 441 and 770); "Lunar Atmospheric Pressure Variations at Glasgow," by R. A. Robb and T. R. Tannahill (*Proc. R.S.E.*, **59**, Part I, 81); "On the Relation between the Stream and Ellipsoidal Constants," by W. M. Smart (*M.N.*, **99**, 561); "The Constants of the Star-streams from the Cape Photographic Proper Motions of 18,323 Stars," by W. M. Smart and T. R. Tannahill (*M.N.*, **100**, 30); and "The Scorpio-Centaurus Cluster (The Southern Stream)," by W. M. Smart (*M.N.*, **100**, 60).

As regards the Taurus Cluster, it has been shown that the Cluster is strongly condensed towards the centre; of 72 cluster-stars 34 lie within a sphere of radius 3 parsecs. The Ursa Major Cluster, on the other hand, is comparatively diffuse; of 42 members only 10 are within 5 parsecs of the centre and the greatest diameter is about 150 parsecs. It has been shown that, contrary to the accepted belief of the last thirty years, the Scorpio-Centaurus Cluster is not a moving cluster but, substantially, a normal sample of B-type stars; the K term is about 5 km./sec. and the mean random speed of the stars is about $6\frac{1}{2}$ km./sec.

Imperial College Observatory, South Kensington
(*Director, Professor H. Dingle*)

The usual routine work of the Observatory was carried on during the earlier part of the year, and preparations were made for the expedition to observe the total solar eclipse of 1940 October 1 in South Africa. The outbreak of war, however, made it necessary to abandon the eclipse expedition, and threatened at first, through the proposed removal of the College to Edinburgh, to cause a suspension of all astronomical work. Fortunately, however, it proved possible to remain in London and to continue, in a somewhat restricted way, the solar and associated laboratory observations. If conditions remain as at present, it is hoped to carry these on during the coming year, and later to resume the courses of instruction to students.

University of London Observatory, Mill Hill, and University College Observatory
(*Director, C. C. L. Gregory, M.A., Wilson Observer*)

(a) *The Radcliffe Telescope.*—8 test plates were taken on 6 nights in order to perfect the adjustments of the instrument. 15 Proper Motion plates of moving clusters were obtained on 11 nights. 8 plates were obtained of Comet Hassel 1913 *d* and 1 plate of the Super Nova in N.G.C. 4636 on 7 nights.

Between March 22 and August 30, 120 parallax plates were obtained

on 48 evenings; between July 11 and August 30, 69 parallax plates on 20 mornings.

The 24-inch and 18-inch objectives of this instrument were removed for safety to the bottom of the hollow pier, 9 feet below ground-level, on August 30. The measurement and reductions of the proper motion plates of the Præsepe, and χ and h Persei clusters, are nearly completed; the comparison plates were obtained at Oxford in 1910. The proper motions which resulted from these measurements appear to be free from magnitude error.

(b) *The Wilson 24-inch Reflector and 4-prism Spectrograph.*—80 spectra were obtained on 70 plates on 35 nights of the following stars: α And, α Aql, γ and κ Cas, α and λ Cyg, κ and 6 Dra, β Leo, α Lyr, ϕ and ψ Per, α Tau, ϵ UMa, α UMi. Considerable progress has been made with the reduction and discussion of these plates.

(c) *The Library.*—Many valuable gifts have been made to the library, including a considerable part of Professor Prager's collection, and a large number of unbound volumes from the Norman Lockyer Observatory. The 1st assistant, Dr. A. Beer, has devoted a considerable amount of time and energy towards completing the library.

(d) *Staff.*—Mr. R. W. Pring, B.Sc., joined the staff as 2nd assistant in May. Mr. P. C. Chaudhuri and Mr. I. H. A. Rahman have continued to work at the observatory as research students.

(e) *Visitors.*—The number of visitors to the observatory during the year was 167.

(f) *University College Observatory.*—The work, which is mostly instructional, has proceeded as usual.

(g) *The Temporary Closing of the Observatories.*—Work ceased, and the observatories were closed, as a protective measure on August 30.

University Observatory, Oxford
(Director, Professor H. H. Plaskett, F.R.S.)

Staff.—Dr. Theodore Dunham, jun., of Mount Wilson, worked at the observatory as Research Associate for some ten weeks in the spring. The first half of Dr. Zanstra's tenure of the Radcliffe Travelling Fellowship was completed in September. He then left Oxford for Pretoria, where he will spend the remaining two years of his fellowship. Apart from these changes and the absence since September of Mr. J. S. Hughes and the Director on active service, the staff remains the same as reported in previous years.

Buildings and Equipment.—The solar telescope and spectroscope were in almost continuous use until the beginning of July. At that time the optical parts were returned to the makers for re-examination and re-figuring. This work was not completed at the outbreak of war, and the optical parts have now been returned to Oxford for safe keeping. Other changes made necessary by the outbreak of war have included the camouflaging of the domes, the internal strengthening of the seismological basement and the sandbagging of the mechanical parts of the solar spectroscope.

Following an invitation from the Board of Visitors, the Society has temporarily transferred its office and the Assistant Secretary, as well as some of its irreplaceable records, to the Observatory.

Astrophysics.—The following investigations have been carried out during the year : (1) Miss Adam has completed the measurement of a group of faint lines near λ 4100, and has established that, like the groups earlier measured by her at λ 5200, they are markedly strengthened towards the limb. (2) Dr. Dunham, using a null photo-electric method with D.C. amplification, succeeded in measuring the profiles of $H\alpha$ and the D lines with the solar spectroscope. (3) Mr. D. S. Evans has completed his study of $H\alpha$ as a function of position on the solar disc, and has shown that uncompensated cycles play a small part in its formation (*M.N.*, **100**, 156). (4) Dr. Zanstra completed his study of radial instabilities in fluid motion (*M.N.*, 99, 499) and was able to establish far-reaching analogies with motions observed in prominences. (5) The Director continued his work on the numerical integration of the equation of transfer for absorption lines, and succeeded in overcoming the greater part of the initial difficulties.

Astrographic Catalogue.—Under the supervision of Mr. H. Scott Barrett, copy for press and plate constants for all 320 plates of the two Potsdam zones $+32^\circ$ and $+33^\circ$ have now been completed. With the aid of a grant from the International Astronomical Union it had been hoped that the printing of the first of these zones would be commenced during the year ; unfortunately, the outbreak of the war and the subsequent increased costs of printing have made this temporarily impossible.

Norman Lockyer Observatory, Sidmouth
(*Director, Mr. D. L. Edwards*)

Staff.—The Research Associate, Professor F. I. Blumbach, left the observatory on June 26 to take up a position at the Physical Institute of Riga University. His place has been taken by Dr. G. Alter, formerly of the Prague University Observatory, who is working under a grant from the Society for the Protection of Science and Learning.

Night Work.—Successful observations were made with one or more instruments on 104 nights out of a possible 110 during the year. The 12-inch McClean telescope was used mainly on spectra of early-type stars for colour-temperature work, also for investigating the photometric effect of fogging background light on such spectra, and for obtaining spectra of ζ Aur during its recent eclipse. The total number of negatives taken was 100. The Kensington 9-inch instrument was used chiefly on Be-type stars, especially γ Cas and ϕ Per, over the region from $H\alpha$ down to about 3500 A. It was also used on some normal B-type stars in the near ultraviolet, and on the above-mentioned effect of light fog. The total number of negatives obtained with this telescope and associated instruments was 60. The Mond astrographic telescope has been used for a survey of open galactic clusters, for the study of which this instrument, with its four simultaneously exposed cameras, is specially suitable. In addition to the

clusters themselves a number of plates was taken for improving the focus settings, and of the North Polar Sequence on all cameras with different plate emulsions. Some photographs were also obtained of Comet Jurlof-Achmarof-Hassel, and of star fields to test the influence of the photometric fog effect on star diameters. The total number of negatives obtained was 170.

Investigations.—Work on the possibility of using objective-prism spectra for determining colour-temperatures has given very satisfactory results. A description of the proposed method and the preliminary results obtained is nearing completion. A survey has been commenced of the galactic clusters, to include the determination of cluster diameters, distances, numbers of stars, magnitudes and colour-indices. The routine procedure has been standardised, and a description of the methods used, with application to one cluster, is ready for the press. Work is being continued on the spectra of a selection of Be-type stars, especially γ Cas and ϕ Per, of which the former continues to show very interesting changes. A new photometric effect depending on the influence of post-fogging background light is being investigated, with special reference to stellar spectra (continuous background and line intensities) and diameters of star images. The characteristics of some photographic emulsions and developers in relation to spectrophotometric work have been studied and the results communicated to the Society. The behaviour of some newly discovered gelatine-liquefying bacteria, which have an exceptionally rapid action on photographic plates, is being examined with the assistance of C. S. Morris and C. V. Watkins of Seale-Hayne Agricultural College, Newton Abbot.

Some mounted photographs of comets and stellar spectra were sent, at the request of the organisers, to the "Hundred Years of Photography" Exhibition held at the Science Museum, London, in July.

Stonyhurst College Observatory
(*Director, Rev. J. P. Rowland, S.J.*)

On the outbreak of war Father Macklin was withdrawn from the observatory to take up duties as a military chaplain, and his place as a part-time assistant was temporarily filled by the Rev. K. O'Callaghan, S.J. Otherwise the staff of the observatory remains unchanged.

The usual routine work of the observatory has been maintained throughout the year.

Drawings of the Sun were obtained on all days on which observation was possible, and these have been supplemented by copies of drawings made at Zürich, kindly supplied by Professor Brunner, to whom have been forwarded copies of the Stonyhurst drawings for a number of days when no observation was obtained at Zürich.

As indicating the progress of the Solar Cycle through the maximum of 1937, the numbers of drawings obtained at Stonyhurst with the numbers of spot-groups observed, and the mean daily spotted area in units 1/5000 of

the visible disc, are exhibited in the following table, except that the measurement of areas for 1939 is not yet completed :—

Year	No. of Drawings	No. of Groups	Mean Daily Area
1936	257	364	5·40
1937	227	422	10·27
1938	241	362	8·31
1939	247	332	...

Considerable activity continued till about the middle of October, after which there was a notable decline.

Counts of groups and nuclei have been sent quarterly to Professor Brunner for the preparation of "Sunspot Numbers" and "Solar Character Figures" under the auspices of the International Astronomical Union.

Dominion Observatory, Ottawa, Canada
(Dominion Astronomer, R. Meldrum Stewart)

Meridian Work and Time Service.—Observations with the meridian circle were continued on the Backlund-Hough star programme and observations were obtained on 119 days. Readings to determine the instrumental constants were taken regularly and the computation of the observations was kept up to date as closely as possible. Observations with the reversible Cooke transit for the determination of clock correction were made on 160 nights. The primary sidereal clocks were compared twice daily and have run without interruption except when Rieflers 75 and 412 were stopped for cleaning and oiling. All the primary clocks have maintained good rates. As in former years, wireless time-signals were received regularly from Rugby, Bordeaux, Nauen, Washington, Monte Grande and Rio de Janeiro. The times of reception of these were sent monthly to the International Bureau de l'Heure at Paris. The new signal clock for operation of mean time-circuits, which was installed last year, has continued to give satisfactory service. In order to maintain the operation of the mean time-circuits with the minimum amount of interruption, a duplicate clock was installed this year. Time-signals were sent out from the Observatory continuously by short-wave radio and over the telegraph lines. The time was also given by telephone when requested. Observatory time-signals were broadcast daily, except Sundays and holidays, by station CBO of the Canadian Broadcasting Corporation, and by station VAA of the Department of Transport. In November the signals to CBO were extended to all the stations of the Corporation and are now broadcast daily. A certain amount of experimental work was done on gravity-impulse pendulums with electrical pick-up. With two different pendulums a considerable improvement in rate was effected by setting the points of pick-up and deposit of the gravity arm well out from zero and on the same side, thus making the period independent of small changes of arc. The experiments are being continued. The synchronized clock systems operated in the various government buildings

in Ottawa have been maintained with a minimum number of interruptions. This service has been extended to new government buildings. The usual number of clocks, chronometers, watches and other timing mechanisms were repaired and rated. Tables of sunrise and sunset, moonrise and moonset for various places were computed and distributed.

Solar Physics.—Atmospheric conditions were again abnormally poor for the best solar spectroscopic observations, though a few of the usual spectrograms at λ 5600 were obtained. The 1911 and 1912 measurements of the solar rotation plates at λ 5600 were corrected for the micrometer-oil error of a little more than 0·01 km. per sec., increased of course by the secant of the component angle. The results still differed systematically from the conventional Faye formula; but they were closely reproduced by the product of the equatorial velocity and the cosine of the latitude to the power 1·315 over their range of 75° in the latitude ϕ. A reasonable correction of a little more than 3 per cent. for the effects of blended spectra enlarges the results to the values from the Greenwich observations of recurrent sunspots, and both are represented by the new formula for the law of the solar rotation, namely, $14^\circ{\cdot}37 \cos^{1\cdot315} \phi$ per day; or $2{\cdot}02 \cos^{1\cdot315} \phi$ km. per sec. From the expansion of the new expression the Faye formula appears as an approximation, its second "constant" increasing with the range of latitude, thus being in the mean one-third greater for spectroscopic than for sunspot measurements.

Fifteen-inch Equatorial.—The observational work during the year was carried on entirely with the photo-electric photometer. Among the stars observed were δ Cephei, ζ Geminorum, α Virginis and η Aquilæ. Routine reductions in connection with these observations were carried out. As in former years the telescope was made available for public demonstration every clear Saturday. As usual, popular descriptions of celestial objects were prepared and printed in pamphlet form for distribution.

Photographic Photometry.—The previous photometric programme was continued with the photographic telescope, some sixty plates of variable-star fields and of the Polar Sequence being obtained. The observations covered the fields of VV Cassiopeiæ, Y Aurigæ, SW Bootis, SU Cygni, RR Cor. Borealis, SV Vulpeculæ and X Vulpeculæ. Measurements and reduction with the Kipp photometer were continued on RZ Cephei, RR Leonis, UX Persei and the Polar Sequence, and previous measures of the field of 12 Lacertæ by the extra-focal method were grouped according to a period in the amplitude of the light curve. This period of 7·496205 days was determined by E. A. Fath from several series of observations made in 1917, 1919, 1920 and 1937. The Ottawa observations were made in 1915–1918.

Meteor Observations.—Observations were made on three showers during the year: (1) In August the visual observations during the Perseid shower were quite gratifying. Rain interfered with the observations only one night during the planned period. A particularly large number were recorded on one of the nights. (2) Better than average weather prevailed for the Leonid shower in November, and observations were carried on for three

nights. (3) In December, during the Geminids, weather conditions were not as favourable, though observations were carried through on one night. Measurements were made of a meteor photograph taken during the Leonid shower last year, and the necessary computations for obtaining its position made.

David Dunlap Observatory, University of Toronto
(Director, Professor R. K. Young)

Spectrographic Work.—Observation on the programme of radial velocity determination of 500 stars in and near the Kapteyn areas reported in the last year's work has been completed and the results published. The area of the sky covered by these regions is approximately 4×4 degrees square. We have since extended this area to 6×6 degrees square and observation is being continued on the additional stars. A programme has also been made out for all those stars in Schlesinger's Bright Star Catalogue for which no radial observations seem to have been determined. During the year 1116 spectrograms were secured on these programmes. Observations of the spectroscopic binaries HD 1826, 22124 have been completed and the orbits are being prepared for publication. A preliminary orbit of HD 9312 has been completed. Observation of the other binaries mentioned in the last report is being continued. Dr. Millman is continuing observation of a number of faint eclipsing binaries. Dr. Heard has been observing a number of Be stars. About 60 plates have been secured and five new Be stars announced. He has also been investigating a number of stars suspected of belonging to the B Canis Majoris type. Dr. Hogg has continued observations of Z Andromedæ and a number of spectroscopic binaries.

Newtonian Focus.—Dr. Hogg has obtained about 40 plates, some with multiple exposure, for the purpose of studying colours, colour distribution and polarization in galactic nebulæ. Mrs. Helen Sawyer Hogg obtained 49 Newtonian plates of globular clusters for the observation of variables. Periods for 36 out of 51 variables in N.G.C. 6934 have been determined to the 6th decimal place and a paper on these variables is nearing completion. A paper on a dozen new variables in N.G.C. 6205, 6366 and 6779 is nearly ready for the printer. Mrs. Hogg has also secured 279 plates of globular clusters in more southerly declinations at the Steward Observatory, Tucson, Arizona, where she was on leave from Toronto for May and June. The variables in these clusters are being studied.

Meteor Observation.—During the Perseid shower of meteors 14 meteor photographs were secured with a multiple rotating shutter camera, one of them being a spectrum. Over 25 direct photographs of meteors were secured at co-operating stations. The orbit and path of a bright meteorite which fell near Dresden, Ontario, has been investigated. Work has also been continued on the study of all meteor spectra photographed here and elsewhere to date.

Instrumental.—The multiple rotating shutter camera used in the above observations, employing six cameras to cover all parts of the sky in the

region of the radiant, has been completed. During the year a Schmidt camera of 3-inch focus was constructed for use with the 74-inch telescope. A blink microscope for the examination of cluster plates has also been completed.

Publications.—"Five Newly Discovered Be Stars." J. F. Heard. *D.D.O., Comm.* No. 4.

"The Radial Velocities of 500 Stars." R. K. Young. *D.D.O. Pub.*, 1, No. 3.

"A Catalogue of 1116 Variable Stars in Globular Star Clusters." Helen B. Sawyer. *D.D.O. Pub.*, 1, No. 4.

Dominion Astrophysical Observatory, Victoria, B.C.
(Head Astronomer, Dr. W. E. Harper)

The observing weather for the year was 18 per cent. below the average. On 177 nights with 1019 hours observing 856 plates were secured. The twenty-one-year average shows 202 nights, 1247 hours and 1319 plates.

Some additions to equipment have been made. A seismograph vault was constructed early in the year, and the instruments formerly used at the Gonzales Meteorological Observatory, about ten miles distant, have been reconditioned and set up here, where the work will be carried out in future. The iris covering the mirror of the 72-inch telescope, formerly opened and closed by hand, can now be operated by motor. Likewise, a motor is to be used for raising or lowering the cassegrain mirror, and these improvements will lessen the manual labour formerly necessary. The 72-inch telescope has been completely rewired for temperature control of the mirror. The stellar photometer for use with the 72-inch has been rebuilt to permit refrigeration of the new Bell Telephone Co. photo-electric cell. Some improvements, based upon experience in its use, have been made in the optical system of the microphotometer, while a second projection machine for measuring spectra has been completed. For some time there has been a desire on the part of the staff to have some machine-shop equipment, by means of which small jobs could be undertaken by themselves. A lathe and drill press and some other small pieces of equipment have now been secured and set up in a suitable room on the ground floor of the dome building.

Mr. Harper was absent from the office the greater part of the year through illness, but in his first few months measured about 150 plates for radial velocity. One double-lined solar-type binary, Boss 2112, was investigated and the orbital elements determined. The period is 11·0764 days, the components are about equal in mass, each having a minimum mass 5 per cent. greater than the Sun. Through measures of the relative intensities of the component lines by the Petrie method, the light ratio of the component stars was found to be 0·7, and this was used in evaluating other physical elements of the system.

Dr. J. A. Pearce continued his observations of eclipsing variables for

the determination of their spectrographic orbits. Definitive elements were deduced from 182 observations of the binary star 57 Cygni (HD 199081). The elements for the epochs 1910, 1934, 1936 and 1939 show that the line of apsides revolves in a period of $25{\cdot}4 \pm 0{\cdot}34$ years. Values of T_0 and ω for 1900 and the secular variations of these elements were deduced. The other orbital elements P, e, V_0, K_1 and K_2 remained constant during the 30-year interval. Preliminary elements were also obtained for the 8th magnitude double-lined class Bo binary HD 1383.

Dr. C. S. Beals continued his programme of observation of interstellar calcium and sodium lines and of P Cygni stars. He was for several months engaged in the preparation of a paper which he presented at the Astrophysical Colloquium held in Paris in July, sponsored by the Fondation Singer-Polignac, and dealing with the general subject of "Novæ and White Dwarfs." In his paper evidence was adduced which suggested that the W stars, the P Cygni stars and the α Cygni stars were all part of a single physical sequence following a different course from the main sequence, and characterized by a very great increase in diameter in passing from the earlier to the later spectral types. Thus the mean diameter for the W stars is of the order of $2{\cdot}5 \odot$, that of the P Cygni stars $12 \odot$ and that of the α Cygni stars $35 \odot$. The corresponding temperatures are 75,000°, 22,000° and 9000°. This sequence exhibits remarkable analogies with successive stages in the development of galactic novæ.

Dr. R. M. Petrie has continued his spectrophotometric studies of double-lined binaries, and has completed the measurement and analysis of 23 such binaries. The differences in magnitude between the components so obtained have been used to determine masses and absolute dimensions. He has also continued re-observing a number of binaries with known orbits. The elements for the double-lined binary HD 23277 have been determined. Since the maximum separation of the component lines corresponds only to 47 km./sec., it can be readily understood how difficult was the problem. Another series of plates of the β Cephei-type star HD 199140 has been secured, and it is expected that the results of a long-continued study of this object will be published soon. Focal-plane curves for the II Moffitt and the II Ross spectrographs have been determined.

Dr. Andrew McKellar completed his study of the isotope effect in the red absorption bands of Li_2. This work, in confirming the validity of measures of isotopic mass ratios by band-spectrum methods, illustrates the important rôle, in the computations, played by the small constants of the third degree in the vibrational energy expression. The α Cygni-type star HD 223385, in the spectrum of which the absorption component of the P Cygni-type $H\alpha$ was once observed to be double, has been kept under observation. The behaviour of the hydrogen lines in the spectrum of this star is apparently similar to those in the spectrum of υ Sagittarii. Several spectrograms of Comet 1939 d, secured in April and May, were the basis of an as yet incomplete spectrophotometric study of the diatomic molecular emission bands. Preliminary results indicate, for a cometary distance of 0·8 astronomical units from the Sun, a "rotational" temperature of about

100° K. Faint R and N spectra are being secured to continue the study of the Swan bands. Three standardized ribbon filament tungsten lamps, obtained some fifteen years ago from the Nela Park Laboratories, Cleveland, have been compared, in collaboration with Dr. Petrie, with a quartz standard lamp calibrated by the firm of Kipp and Zonen, Holland. No systematic difference in the calibration curves of the D.A.O. lamps and quartz lamp were found.

Mr. K. O. Wright continued his spectrophotometric study of solar-type stars. Equivalent widths of 600 lines in each of the stars, the Sun, γ Cygni, α Persei and α Canis Minoris, were determined, and these were used to construct curves of growth for these stars. From these, turbulent velocities and also excitation temperatures were determined. The work is now being written up as a thesis for the Ph.D. degree at the University of Michigan.

Mr. Walter H. Stilwell, who came to us at the beginning of the year from the Lick Observatory, has been engaged in a determination of the radial velocities of the stars in the Taurus cluster. The Lick Observatory was kind enough to loan for measurement many plates he had obtained in the preceding year, and these will be supplemented by others made with the 72-inch here.

Mr. William Petrie, summer student assistant, was engaged in determining the radial velocities and spectral line intensities of the star ι Herculis. Using 52 high dispersion spectrograms, he confirms a variation of 15 km./sec. in the velocity, but no period was found. Spectrophotometric studies of line intensities failed to confirm Edwards's period of variation of 0·1434 day, and it is doubtful if any real change in absorption is present.

Miss Phœbe Riddle, volunteer assistant, carried through two least-squares solutions for the orbital elements of the binary κ Cancri. She also assisted with the Saturday night visitors.

Including daytime visitors, approximately 2366 persons visited the observatory during the year.

Six numbers of the *Publications D.A.O.* were distributed :

Vol. vii, No. 3—"The Definitive Orbit of the Spectrographic Binary β Arietis," by R. M. Petrie.
4—"The Spectrographic Orbit of HD 195986," by Andrew McKellar.
5—"One Hundred and Thirty-two New Variable Stars in Five Globular Clusters," by Helen B. Sawyer.
6—"The Calculation of Rotation Factors for Eclipsing Binaries," by R. M. Petrie.
7—"The Spectrographic Orbit of Boss 3511," by W. E. Harper.
8—"The Spectrographic Orbits of the Components of Boss 2112," by W. E. Harper.

Fourteen separate papers for scientific meetings were prepared, 10 lectures and 11 broadcasts were given by members of the staff.

Helwan Observatory, Ministry of Public Works, Egypt
(*Director, Dr. M. R. Madwar*)

Time-Service.—The time-service was maintained as usual, the error of the standard sidereal clock Shortt No. 1 being determined from star transits. Rhythmic W/T signals were received daily from Bordeaux and Rugby, and the times of the first and last signals were used for comparison.

Shortt No. 1 stopped on July 17, owing to a failure in the remontoire of the free pendulum. After some trouble in securing a good vacuum, it was restarted on August 21 ; it ran satisfactorily during the remaining period.

A mean time synchronome clock Shortt No. 65 was erected during the summer and has since been used as standard civil time clock.

The reversible transit was used regularly, and 27 transits were taken throughout the year.

Reynolds Reflector.—The reflector was used on 87 nights. 92 plates were exposed : 60 on nebulæ, 6 on comets, 24 on planets and 2 on test plates.

The positions of Comet Peltier were communicated to the Bureau Central des telegrammes astronomiques.

Mars was observed during the last opposition, 22 plates were exposed with different filters, and visual observations were made on 8 nights for identification of marks.

Nizamiah Observatory, Hyderabad
(*Director, T. P. Bhaskaran, M.A.*)

Observations with the astrographic telescope were continued on the same lines as in previous years ; 109 repetition plates were taken during the year, in the regions of the Hyderabad astrographic zones, for comparison with the plates of the earlier series.

Early in February 7 photographs of Comet 1939 *a* (Kosik-Peltier) were taken with the 4-inch astro-camera temporarily attached to the tube of the astrographic telescope.

The blink comparator continued to be in regular use for the comparison of astrographic plates, and 143 areas (with centres in Declination $-18°$ and $-19°$) were examined during the year. Excluding stars of known proper motion, the number of stars with motions exceeding $0''{\cdot}15$ per year was 130.

The printing of vol. xi (Zone $+37°$) of the Hyderabad *Astrographic Catalogue* was completed and copies have been distributed. The whole of the MS. of vol. xii (Zone $+36°$) is in the hands of the printers, with the exception of the introduction and tables, and it is hoped that the volume will be ready for publication during 1940.

Observations of variable stars (mostly with faint minima) were continued with the Grubb refractor ; although the observing weather was much below the average, 1639 estimates of visual brightness were obtained during the year.

The number of occultations of stars by the Moon observed was 49 (disappearances 35, reappearances 14). All the occultations observed in 1938 have been reduced and the results published in the *Monthly Notices*.

A Hale spectrohelioscope made by Howell and Sherburne, Pasadena, has been added to the equipment of the observatory. A suitable observing house has been designed and is under construction. The instrument will be erected as soon as the reinforced concrete piers for supporting it are ready.

As usual, observations with the transit instrument have been made about once a week on the average, for the determination of the error of the standard clock.

Kodaikanal Observatory
(*Director, Dr. A. L. Narayan*)

The usual programme of work has been continued. Photoheliograms were obtained on 330 days, calcium flocculi plates on 317 days, calcium prominence plates on 305 days and *Hα* flocculi plates on 284 days. Prominence plates in *Hα* light were also taken on a few days when there were active prominences. One calcium flocculi plate for each day was sent to the Solar Physics Observatory, Cambridge, as in former years.

Under the auspices of the International Astronomical Union, K prominence and *Hα* disc spectroheliograms were collected from other observatories whenever complete observations were not possible at Kodaikanal. The statistical data regarding prominences seen at the limb and by absorption on the disc were published in the half-yearly bulletins of this observatory.

Daily character figures of solar activity according to *Hα* bright flocculi and *Hα* dark markings have been communicated to the Observatoire Fédéral, Zürich, for inclusion in the Bulletin of Character Figures published by the International Astronomical Union. Daily character figures as derived from calcium flocculi from Kodaikanal photographs are communicated for publication by the Solar Physics Observatory, Cambridge.

Observations with the Hale spectrohelioscope were made on all days of favourable weather except on Sundays and holidays, special attention being given to bright chromospheric eruptions. A list of these eruptions, together with the times when the Sun was under observation, was sent quarterly to the Meudon Observatory, Paris, for inclusion in the Bulletin of Character Figures. The displacements observed in the prominences and in *Hα* dark and bright markings are summarised in the half-yearly bulletins of this observatory.

Instruments.—The Director has designed, built and fitted up an amplifier to the photoelectric microphotometer at the observatory. The electrical system is the familiar single-tube circuit. The valve used is of type 2A6, a Duplex diode High Mu Triode with a high transconductance.

Research Work.—A paper on "The Bright Solar Eruption of March 3, 1939," by Messrs. M. Salaruddin and C. K. Ananthasubrahmaniam was

published in the July number of the *Proceedings of the Indian Academy of Sciences.*

Messrs. M. Salaruddin and B. G. Narayan have made a detailed study of the "Unusual Solar Activity" during 1939 August and September. A preliminary note on this was sent to the *Observatory* for publication, and a paper giving full details is in press.

The Director, M. Salaruddin and C. K. Ananthasubrahmaniam were engaged in a spectrophotometric study of the strong Fraunhofer lines in the region of the Magnesium *b* group and the infra-red triplet of oxygen at λ 7774. Spectrograms of the *Mg* triplet were taken in the 3rd order of the 20-ft. Littrow spectrograph ; those of the oxygen triplet were obtained in the 2nd order. A double monochromator, which allows only a small region of wave-lengths to enter into the spectrograph and cuts off all scattered light, was used to improve the purity of the spectrum in the spectrograph. Intensity profiles were measured at different points of the Sun's disc and at the equatorial and polar limbs.

Dr. A. K. Das and Mr. B. G. Narayan have continued their study of prominence areas to determine the possible influence of the Earth on solar phenomena and have prepared a paper for publication.

A theoretical investigation on the mechanism of formation of solar dark markings has been undertaken by Dr. A. K. Das and a paper is in preparation.

Mr. P. R. Chidambara Iyer has continued his statistical investigation on "The Relative Variations in the Extents of the Bases and in the Heights of Prominences accompanying Variations in their Areas."

Mr. M. Salaruddin has been making a statistical study of the short-lived hydrogen absorption markings. A statistical study of Doppler displacements on the disc and limb of the Sun has also been undertaken by Mr. B. G. Narayan.

Mr. M. Salaruddin has been awarded the M.Sc. degree of the Andhra University for his thesis on "The First Spark Spectrum of Bromine and the Hyperfine Structure of some Complex Lines."

Union Observatory, Johannesburg
(*Union Astronomer, Dr. H. E. Wood*)

26½-Inch Visual Refractor.—2427 visual micrometrical measures of double stars were made during the year and 6 photographic plates were obtained. Some drawings of Mars were made near the time of opposition, and experiments on cinematographic observations of the planets were carried out.

Occultations of Stars by the Moon.—104 observations of occultations of stars by the Moon were obtained during the year.

The results of the year's observations are given below ; the second column indicates the time by which the Moon has arrived too early at any longitude, and the third column the amount by which the Moon is ahead of its tabular longitude.

		s	"
	1939·08	3·8	2·1
	·41	4·8	2·8
	·62	3·5	2·0
	·88	0·4	0·3
Mean for year	1939·57	3·3	1·9

These results are, as in former reports, deduced from disappearances at the dark limb only. In obtaining the means, each occultation is given a weight equivalent to cos $(\chi - \rho)$, and no occultation is included for which the value of cos $(\chi - \rho)$ is less than 0·5.

Franklin-Adams Star Camera.—During the year 647 plates were taken with this instrument. The distribution of the plates was as follows :—

Variable Star Regions	...	...	252 plates.
Minor Planet Regions	...	...	271 ,,
Comet Regions ...	...	...	124 ,,

Comet 1939 *a* (Kosik-Peltier) was observed from February 14 to April 21, 54 positions being obtained. Comet 1939 *c* (Pons-Winnecke) was observed from June 27 to September 4. Comet 1939 *e* (Kopff) was observed from April 26 to May 26. An unidentified object was discovered by Mr. C. Jackson on June 12 ; this was later found to be Comet 1925 II Schwassmann-Wachmann and was designated Comet 1939 *f* ; it was observed from June 12 to June 21. A search was made for Comet 1939 *i* (Kamensky) on August 5, 7 and 9, but this object could not be found. Comet 1939 *k* (Tuttle) was observed from November 10 to December 31. Plates were exposed for Comet 1939 *n* (Friend) on December 14, 15, 20, but the comet was then evidently too faint.

25 new minor planets were discovered during the year, and elliptic orbits were computed for 7 minor planets.

390 approximate positions and 45 accurately measured positions of minor planets were sent to the Astronomisches Rechen-Institut.

Union Observatory Circulars.—Circular No. 101 was published and distributed during the year.

Miscellaneous.—Professor E. Hertzsprung visited the Observatory from January 13 to March 14 for the purpose of installing the new twin 16-inch photographic telescope for the Leiden Rockefeller Foundation. Dr. A. de Sitter left on February 21, and Dr. W. Chr. Martin arrived from Leiden on March 4. Dr. H. van Gent also returned from Leiden on December 17.

The number of visitors to the Observatory during the year was 1517.

Radcliffe Observatory, Pretoria
(*Director, Dr. H. Knox-Shaw, Radcliffe Observer*)

Early in the year such of the necessary adjustments as were possible without the mirrors were made to the 74-inch reflector. It had been expected that the large mirror would be figured by about the middle of the year, but unfortunately it was still unfinished when on the outbreak of war

Sir Howard Grubb, Parsons & Co. were obliged to cease work on it. As a precaution it has been buried in a hole under sandbags, but it is hoped that arrangements will soon be made for its completion. A similar fate has overtaken the Cassegrain spectrograph. The optical parts have been delivered by Adam Hilger Ltd., but the frame lies uncompleted in the shops of C. F. Casella & Co.

Dr. R. O. Redman took up residence at the observatory in March, and Dr. H. Zanstra, the first holder of the Radcliffe Travelling Fellowship in Astronomy, after spending two years in Oxford, came out in September. Dr. Redman and Mr. Williams have been employing the 7-inch finder of the reflector on the photographic photometry of B stars and eclipsing variables. The measuring machine, described by Dr. Redman in *M.N.*, **99**, 686, has been converted into a photo-electric photometer for temporary use in connection with this work. The 3-inch refractor has been employed for observing occultations. A paper on Nova Herculis by Mr. Williams appeared in *M.N.*, **99**, 61, and a description of the observatory was contributed to *Occasional Notes* by the Director.

Commonwealth Solar Observatory, Canberra, Australia
(*Director, Dr. R. v. d. R. Woolley*)

Solar Radiation.—The determination of the water-vapour content of the atmosphere w in the path of the Sun's rays, as outlined in the reports of previous years, has been continued. Using Kimball's curves (which give the transmission coefficients for various air-masses and water-vapour contents), residuals representing the depletion of solar radiation by atmospheric dust were obtained.

An analysis of the pyrheliometric observations for 155 very clear cloudless days during the past four years has been made. On such days there was practically no haze or meteorological corona around the Sun. The residuals representing dust depletion should all be of the same order. It has been found, however, that for small values of w the residuals were much larger than the mean, while for large values of w the residuals were almost invariably negative. This suggests that Kimball's results require to be modified to permit of general application.

Solar Spectroscopy.—The influence of the Stark effect on the damping factor in the Sun has been determined by plotting the curve of growth for a number of iron lines. The oscillator strengths were evaluated by measuring line intensities in an iron arc. The value of 14 dynes per cm.^{2} was obtained for the electron pressure of the reversing layer.

Solar Activity and Eruptions.—Regular direct photographs of the Sun's disc with the Farnham telescope were discontinued in September, and were replaced by sketches made with the Sun telescope. A camera for direct photography of the Sun with the Sun telescope has been constructed.

Routine observations of the solar disc with the Hale spectrohelioscope have been continued. Spectrohelioscopic studies of bright chromospheric

eruptions have been directed to their intensities, velocities, the width of $H\alpha$ and the level in the chromosphere.

Spectra of bright eruptions on the Sun's disc have been studied with a microphotometer to detect evidence of emission lines. To date 116 emission lines have been detected in the visible part of the spectrum. These lines are mainly those that are strong in the chromosphere, but all Fe^+ lines and low-level *Fe* lines show an abnormal enhancement in eruptions.

Observations of effects produced in the Earth's ionosphere by solar eruptions have been continued.

A theory has been suggested for the motion of eruptive prominences associated with eruptions.

Cosmic Radiation.—Continuous records of the intensity of cosmic radiation have been maintained, making a total of over four years of observation. The records are in course of reduction.

Publications.—Publications include "Fraunhofer Intensity Table, 3924–4300 A.," Memoir No. 6 of the Commonwealth Solar Observatory; "The Conduction of Electricity in the Lowest Levels of the Atmosphere," Memoir No. 7; "The Relations between Eruptions and Sunspots," *Ap. J.*, **89**, 555, 1939; and "The Association of Radio Fade-outs with Solar Eruptions," *Terr. Mag.*, **44**, 181, 1939. The following contributions are in course of publication: "Atmospheric Potential Gradient Measurements," Memoir No. 8; "Solar Eruptions" and "The Motions of Eruptive Prominences," *Ap. J.*; "Stark Effect and Damping Factor in the Fraunhofer Spectrum"; "Photometry of Solar D Lines"; "The Spectrum of Bright Chromospheric Eruptions," *M.N.*; "The Intermediate Ions of the Atmosphere," *Proc. Phys. Soc.*; and "Air-Earth Current," *Quart. J. R. Met. Soc.*

Staff.—The Director took up his duties at the Observatory on 1939 December 4. Mr. R. G. Giovanelli, Research Fellow, resigned in 1939 August. During his two years at the Observatory he had charge of the Hale spectrohelioscope routine, and carried out a number of researches on solar eruptions. The professional staff at the Observatory at present consists of Director, Dr. R. v. d. R. Woolley; Assistants, Mr. W. B. Rimmer, Mr. A. R. Hogg, Mr. A. J. Higgs and Dr. C. W. Allen.

Melbourne Observatory

(Director, J. M. Baldwin, M.A., D.Sc., F.Inst.P., Government Astronomer)

The observation of stars of the Provisional General List of Fundamental Stars has been continued during the year, the number of observations obtained being 1452 in R.A. and 595 in Dec. The small number of observations is accounted for by the fact that the programme is almost completed.

The visual observation of long-period variable stars has been continued, 1570 observations being obtained. The results have been forwarded to Harvard College Observatory each month, for publication with those of other members of the American Association of Variable Star Observers.

Observations of occultations listed for Melbourne in the *Nautical Almanac* have been made when possible. The occultations observed in 1938 have been reduced and the results forwarded to the Nautical Almanac Office. The reduction of the occultations observed in 1939 will be commenced very soon.

A large amount of time has been devoted to the revision of Volumes 4 and 5 (Zones $-71°$ to $-74°$) of the *Astrographic Catalogue*, and the definitive plate constants have now been computed up to $-86° 6^h$. Three outstanding plates have been measured.

The magnetic variometer house at Toolangi was completely destroyed in the bush fires on January 10, and no part of the Eschenhagen recording instruments or of the accessories could be saved. The absolute house and the absolute instruments were fortunately unharmed. A new variation house has been built, the new building being of concrete and underground. All material used in the construction was tested and found free from magnetic substances. Through the kind interest of Dr. Lacour, a complete set of Lacour magnetic variation instruments and accessories have been generously lent by the International Polar Year Commission. The instruments were installed during December and are now registering.

Riverview College Observatory, Riverview, N.S.W.
(*Director, Rev. D. O'Connell, S.J.*)

Father W. J. O'Leary, S.J., former Director of the observatory, died suddenly in April 1939. He had just constructed a blink comparator of a new design, with which he discovered a number of new variable stars, some of them the evening before he died. Work on them will be continued. Another assistant will shortly join the staff. Dr. J. Voûte, Director of the Bosscha Observatory, Lembang, spent the latter half of 1939 at Riverview working on the plates. He has completed studies of several variable stars, some of which will be published at Lembang and others in *Riverview Publications.*

A new camera, with an $f/4{\cdot}5$ lens of 4 inches aperture, was received during the year from Grubb, Parsons & Co. The cost was defrayed in part by a grant from the Council for Scientific and Industrial Research. It is being used mainly for variable star work.

Owing to unfavourable weather the number of occultations observed was much smaller than usual. The reductions are made by the Computing Section of the B.A.A. and published in the *B.A.A. Journal.*

Publications.—Riverview Publication 5, containing papers on variable stars, will be distributed shortly.

Sydney Observatory
(*Director, Mr. James Nangle, O.B.E., Government Astronomer*)

Volumes 13 and 14 of the Sydney Section of the *Astrographic Catalogue* have been printed and were distributed in May. Volume 22 is at present

in the hands of the printer. During the year the measurement of plates and preparation of manuscript has continued, and there are now four volumes ready to go to the printer and thirteen more are in an advanced stage. Observations of reference stars have been continued with the 6-inch transit-circle.

The occultations predicted in the *Nautical Almanac* have been observed when possible. The reductions of the 1938 occultation observations were made in duplicate and one set forwarded to Yale Observatory as suggested by the Astronomer Royal.

To date, December 12, ninety-nine earthquakes have been recorded by the Milne Seismograph.

The civil work of the observatory has been continued as usual. This consists chiefly in the supply of astronomical memoranda, astronomical information for legal purposes, and the time service.

The educational work of the observatory has been continued this year and lectures on Astronomy have been delivered regularly. More than 1600 persons who visited the observatory during the year were shown the uses of the various instruments and on fine nights were given the opportunity to look through the telescope. Lectures and demonstrations were given to students of the University and Teachers' College.

Carter Observatory, Wellington, New Zealand
(*Director, Mr. M. Geddes*)

This observatory was established by Act of Parliament towards the end of 1938 and began to function in 1939 April. The present staff consists of the Director and one assistant (Mr. I. L. Thomsen). At present only temporary premises are available, but it is expected that a new building will be erected early in 1940.

The temporary nature of the accommodation and the general work of organisation have somewhat limited the opportunities, but a start has been made with a programme of research which has been further hampered by the very cloudy skies experienced during the year.

9-inch Refractor.—This has been employed mainly in the measurement of double stars and for planetary work. The very favourable opposition of Mars in July gave an opportunity for a close study of the surface features, and it is intended to publish the results at an early date. A small amount of work has been done on Jupiter, chiefly in the timing of central meridian transits of markings. Photographic work with the instrument has been confined chiefly to experimental work on open star clusters, double stars and minor planets.

Solar Work.—General routine observations of sunspots have been made with a 5-inch refractor on all clear days. When the weather has been suitable spectroscopic observations of prominences have been made, usually with the 9-inch refractor. Arrangements are at present being made to secure the loan of a spectrohelioscope from the Mount Wilson Observatory.

Auroræ.—Two photographic stations have been maintained in Southland and all the larger displays have been photographed. In addition, observations of all displays have been collected from voluntary observers throughout the country, approximately 133 auroræ having been recorded during the year.

Visitors.—During the eight months that the observatory has been open to visitors 1281 persons have attended on public and special nights.

Dominion Observatory, Wellington, New Zealand
(*Acting Director, R. C. Hayes*)

Early in 1939 the astronomical work of the Dominion Observatory (with the exception of the Time Service) was handed over to the newly established Carter Observatory. The Dominion Observatory's astronomical library, and most of its astronomical equipment, have been made available to the Carter Observatory, on loan.

The New Zealand Time Service was maintained throughout the year by the Dominion Observatory.

Publications issued by the Dominion Observatory included a paper on the "Photographic Determination of the Height and Position of Auroræ in New Zealand in 1937," by M. Geddes; two Time Service *Bulletins*; and the "Annual Report of the Dominion Observatory for the year 1938."

Mr. Robert Barker's Observatory, Cheshunt, Herts

Lunar work included further investigations of the almost uncharted formation Sven Hedin, and extension of a newly discovered tributary cleft to Sirsalis.

Observations on Mars, though few, revealed much detail around zero longitude. Over 40 canals were charted during the opposition, including two never before seen in England.

Determinations of variability in the Saturn satellites Dione, Tethys and Enceladus have been made, the "black-out" skies affording much assistance.

Mr. Evershed's Observatory, Ewhurst, Surrey

Spectroheliograms in *Hα* light were obtained on 138 days during 1939. These are on exactly the same scale as the Kodaikanal photographs, and any negatives required to fill gaps in the Kodaikanal series have been sent there for measurement, as in former years. Estimates of character figures and records of bright eruptions have been sent to Zürich and Meudon respectively.

Measures of the H and K lines in prominence spectra secured during the period of maximum solar activity have been reduced and summarised, and indicate an increase of the mean daily angular rotation ξ for all latitudes, compared with the period of minimum activity, from 15°·5 to 16°·9. This

is for the stable prominences at a height of about 30″. There appears to be no marked change of angular rotation speed with latitude, as is the case in the reversing layer.

Measures of the solar rotation in the reversing layer obtained from spectra photographed during the years 1928–35 inclusive have also been summarised, and clearly show the increase of angular speed with height above the photospheric level. At the solar equator $\xi = 15°{\cdot}6$ for the high-level lines H3 and K3, $14°{\cdot}1$ for the intermediate level of the sodium and magnesium lines and $13°{\cdot}8$ for low-level iron lines.

In this work the method of simultaneous exposures for east and west limbs described in *M.N.*, **93**, 165, has proved its great value, especially in providing the most suitable material for the positive-on-negative method of measuring. During December of the past year a series of rotation spectra has been secured in the red with 12 transmissions through the liquid prism. This is in order to investigate some rather baffling anomalies that have occurred in this work, and which probably account for the varying results of different observers.

Other work with the liquid-prism spectrograph has been the photographing of the sodium lines in the solar spectrum at λ 5682 and λ 5688 with vacuum tube comparison spectrum. The measured shifts of these lines at the centre of the Sun have been found to agree closely with the shift of D1 and with the theoretical relativity shift.

The Zeeman doublet in spot spectra at λ 5250·218 has been photographed with 8 and 10 transmissions through the prism, and interesting details have been disclosed. It is found that in the penumbræ, either on one side only or on both sides of spots, the line is a clearly resolved doublet, increasing in separation towards the umbra, but without any trace of a central component. Over the umbral region, on the other hand, the line appears as a triplet, when sufficient exposure has been given, the central line being conspicuous and the side components faint and ill-defined.

Publications.—"New Measures of the Wave-lengths of the Calcium Lines K and H," *M.N.*, **99**, 120; "Note on the Zeeman Effect in Sunspot Spectra," *M.N.*, **99**, 217; "Measures of the Relative Shifts of the Line 5250·218 and Neighbouring Lines in the Mt. Wilson Solar Magnetic Field Spectra," *M.N.*, **99**, 438.

Dr. J. L. Haughton's Observatory, Teddington

Owing to illness in the early part of the year and the weather in the latter part, very little observational work has been carried out. Only four occultations have been observed and many fewer nova search photographs have been taken than in previous years.

On the other hand, the 8″ mirror, whose purchase was mentioned in an earlier report, has been fitted up. In order to carry it on the same equatorial mounting as the 4″ refractor, an open tube has been built in magnesium alloy. This tube, which with its adjuncts weighs 22 lb., would have weighed nearly 1 cwt. in iron and would have been much too heavy for the mount.

Mr. M. B. B. Heath's Observatory, Kingsteignton, Devon

Daylight observations of Mercury were made on 16 days, and of Venus on 17 days, mostly near superior conjunction. Mars was observed on 50 nights and 22 drawings were made. Among other occasional phenomena the occultation of Uranus on January 1, the partial eclipse of the Sun (measured local magnitude 0·32) on April 19 and the lunar eclipse of October 28 were observed.

Mr. F. M. Holborn's Observatory, Streatham

Observations were made on 173 nights. Four visual observations of brightness were made of Nova Herculis (1934) and one of Nova Lacertæ (1936). γ Cassiopeiæ was observed on 100 nights. 1927 observations were made of 63 variable stars. A few drawings of Mars were made near opposition. The Sun was observed on 196 days, on 92 of which one or more naked-eye spots were seen.

Records of all the above were communicated to the British Astronomical Association.

Mr. A. M. Newbegin's Observatory, Worthing, Surrey

The number of observations was somewhat less than in the previous year, mainly on account of adverse weather conditions, especially in the last three months of the year.

The mean daily frequency for prominences was 9·18, and indicates a distinct drop. There was also a marked decline in their quality, and it frequently happened there were days when the prominences were more like those of the minimum period. Occasionally a striking display was observed, and the highest prominence seen during the year reached 225″ of arc in height. The distribution was almost equal for both hemispheres and throughout the year was remarkably constant. Metallic activity was seen in 16 prominences compared with 57 in 1938.

Sunspots maintained their mean daily frequency much better, and the figures at 7·67 are practically the same as in 1938. For the whole year the southern hemisphere was slightly the more active, except in rotation No. 1146 (May and June), when activity was in excess in the north.

Observations with the spectrohelioscope were made on 93 days and 146 chromospheric eruptions were recorded, details of which were sent to Meudon for inclusion in the *Quarterly Bulletin on Solar Activity*. A very remarkable eruption occurred on September 8 over a group of sunspots in lat. S. 15°, long. 222°. Radial velocities are often observed in these bright eruptions, usually of the order of 50 km./sec., but in this case the velocity was 142 km./sec. outwards, a speed believed to be rare in connection with chromospheric eruptions. Moreover, the changes in form were very rapid after the maximum intensity.

Work with the Coudé equatorial has been in abeyance throughout the year, largely on account of the illness of Mr. Bernard Pitcher.

Mr. B. M. Peek's Observatory, Solihull, Birmingham

Photometric observations of Nova Persei 1901 have been continued, and a few observations have been made of the irregular variables U Geminorum and SS Aurigæ.

Twelve occultations of stars by the Moon were recorded in 1939.

As in past years, visual observation of the planet Jupiter has constituted the main part of the programme. Observations of dark projections at the south edge of the N. Temperate Belt, obtained on the nights of October 7 and 9, enabled the announcement to be made that these objects had once again a remarkably short rotation period, of the order of $9^h\ 49^m$.

The Rev. T. E. R. Phillips's Observatory, Headley

The usual routine work has been continued.

Observations of Mars were made about the time of the planet's close approach, but its great S. declination rendered the detection of delicate details impossible. Some interesting large-scale features were, however, recorded.

As usual Jupiter and Saturn have been systematically observed, and over 1900 longitude determinations of Jovian markings were secured. The outstanding features of the apparition of Jupiter were: (*a*) another outbreak of rapidly moving spots at the S. edge of the N. Temperate Belt (rotation period about $9^h\ 49^m$), and (*b*) a marked increase in the rotation period of the Great Red Spot.

Owing to absence from Headley and other causes, Dr. Waterfield has been unable to carry out a systematic photographic programme.

Mr. P. M. Ryves has been in Headley throughout the year, and has made a large number of observations of variable stars.

Micrometer measurements of double stars with the 8-inch refractor have been continued.

Mr. F. J. Sellers's Observatory, Muswell Hill, London

The 5-inch equatorial has been employed in daily telescopic and spectroscopic observations of the Sun as usual. The summaries of these, which have been published in the *B.A.A. Journal*, give evidence of a general decline in solar activity during the year in spite of periods of recrudescence.

The spectrohelioscope has been in daily use whenever possible to record disc phenomena, 64 bright chromospheric eruptions having been reported to Meudon, and included in the I.A.U. *Solar Bulletin*, during the first eight months of the year. Other observed disc phenomena have been described and discussed in the solar summaries in the *B.A.A. Journal.*

The weather during the latter part of the year has greatly interfered with observational work.

Some lunar occultations have been observed with the 8·5-inch reflector and reduced for communication to the B.A.A.

Dr. W. H. Steavenson's Observatory, West Norwood

Up to the end of August the 20-inch Hindle reflector was in use at Norwood for photometric observations of faint novæ, as in previous years. Some of the results have been communicated to the Society.

Meanwhile, largely through the skill and generosity of Mr. J. H. Hindle, a 30-inch reflector of 10 feet focal length has been added to the equipment. Owing to the progressive deterioration of local observing conditions it had been decided not to mount this instrument in the London area, and it has now been erected in the paddock which lies to the north of the main building of the University Observatory, Cambridge, by kind permission of the Director.

The dome which covers the reflector was designed by Mr. L. A. Cox, and actually put together by Dr. Woolley, with some volunteer assistance. It is hoped later to use the instrument mainly for visual photometry, but it is meanwhile at the disposal of the staff of the University Observatory for any work that may be thought suitable for it.

Wolsingham Observatory (Rev. T. E. Espin's), Tow Law, Co. Durham (Observer, W. Milburn)

The survey for new double stars in the unexamined parts of the B.D. zones was continued with the 24-inch Calver reflector in the early part of the year.

The mirrors were resilvered at the observatory in the summer.

Owing to A.R.P. activities and lighting restrictions observing was discontinued, except for the use of the 5-inch refractor for the benefit of visitors.

REPORTS ON THE PROGRESS OF ASTRONOMY

THE STATISTICAL THEORY OF ERRORS

The object of this report is to give a very brief account of the theory of the Combination of Observations from the point of view of the comparatively recently developed science of Statistics. The statistical problems of interest to the astronomer may be divided roughly into two classes. Firstly, there are the problems of *estimation*, in which we have to decide what value to adopt for some quantity of which we have a series of observations. The quantity may be a simple observable such as the position of a star, or a more complex one such as the constant of nutation or a correlation coefficient. The second type of problem concerns the *significance* of the results. Thus, having found a correlation coefficient of 0·40 from ten observations of two quantities, we may ask what are the chances of finding a correlation coefficient arithmetically greater than 0·4 when the true value is zero.

Problems of Estimation.—Two concepts are fundamental, "*population*" and "*sample*", and the distinction between these must be clearly maintained. In the case of measurements, the population is regarded as the aggregate of all possible measurements of the quantity in question, and will therefore have well-defined characteristics such as the mean value and the mean square deviation, or "variance" as it is usually termed in statistical literature. If we take a finite number of observations this will constitute a sample, and the mean and the variance of the sample will not in general be the same as those of the population. As the sample gets larger they will approach, though not monotonically, the corresponding values for the population. In practice, however, we are usually restricted to relatively small samples, and the problem is to say something about the population from an examination of the sample. To take a typical example, let us suppose that we have six observations of the position of a spectral line, and we wish to adopt a value for the true position. If we were to make six million observations we should feel justified in saying that the arithmetic mean of these was the true position, as measured by the instrument used. But if we found the median (the value which has the same number of observations on either side) or any weighted mean, we should find practically the same value, assuming a symmetrical error distribution. In the case of a small sample of six observations the various means will usually be different, and we are led to ask if the arithmetic mean has any special virtue that we should always use it. The following considerations will give us the answer. Suppose we were to make a large number of sets of six observations, then the arithmetic means of these samples would vary, and if we had enough we could find the number lying in any particular region, obtaining, let us suppose, the distribution curve A which should be symmetrical about M, the mean of the population. M, as we have seen, is independent of the

particular method (median, arithmetic mean, etc.) by which it is found, and may be called the true value of the quantity measured. Taking now, for example, the median, we find the corresponding curve *B*. If the curves

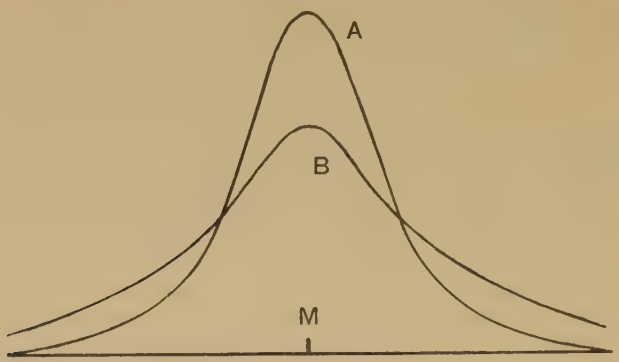

FIG. 1.

are as shown in the figure it is clear that in this case it is preferable to use the arithmetic mean, as there is a greater chance of being nearer to *M* than if we use the median. Stated precisely, the mean square deviation or variance of the arithmetic mean is here smaller than that of the median. In the case where the distribution of the measurements follows the ordinary Gaussian error law, we can show (1) that the variance of the median is $\frac{\pi}{2}\sigma_1^2$, where σ_1^2 is the variance of the arithmetic mean, the number of observations in the sample being the same in each case. If this number be n, we have $\sigma_1^2 = \sigma^2/n$, where σ^2 is the variance of the individual measurements. Thus to obtain the same variance for the median we should have to take $\frac{\pi}{2}n$ observations in each sample—strictly speaking at least $\frac{\pi}{2}n + 1$. It is usual to express this by saying that the "*efficiency*" of the median is only $2/\pi$, or 64 per cent. of that of the arithmetic mean. In the case of a Gaussian distribution the arithmetic mean is the most efficient statistic we can use.

Suppose, however, that the observations do not follow a Gaussian distribution. It is then no longer true that the arithmetic mean is necessarily the most efficient statistic for calculating the true mean (of the whole population). Fortunately it is possible to combine the values observed to give us the most efficient statistic in the above sense—provided that we know the law of distribution of the observations. Suppose the chance of an observation falling at distance $\epsilon \pm d\epsilon/2$ from the mean is given by

$$y d\epsilon = f(\epsilon) d\epsilon.$$

If the actual observations are $x_1, x_2, \ldots, x_n$, the probability of such a sample occurring is proportional to

$$f(x_1 - \mu) f(x_2 - \mu) \ldots f(x_n - \mu) dx_1 dx_2 \ldots dx_n, \qquad (1)$$

where μ is the true but unknown value of the mean. It is important to realise that we may not invert this statement and say that, since $x_1, x_2, \ldots, x_n$ are actually observed, then

$$f(x_1-\mu)f(x_2-\mu)\ldots f(x_n-\mu)d\mu \tag{2}$$

is proportional to the probability that μ lies in the range $\mu \pm d\mu/2$. It is worth while considering the implications of such a statement. Let us first suppose that we have some prior knowledge of μ, and are able to say that before making the observations the probability that μ lies in the interval $\mu \pm d\mu/2$ is $\phi(\mu)d\mu$. Then the probability of having both μ and $x_1, x_2, \ldots, x_n$ within given ranges is

$$\phi(\mu)d\mu\,.f(x_1-\mu)\ldots f(x_n-\mu)dx_1\ldots dx_n.$$

The total chance of drawing a sample $x_1, x_2, \ldots, x_n$, whatever the value of μ, is the integral of this quantity over all values of μ. Hence the probability, after the observations, that the mean actually has a value $\mu \pm d\mu/2$ can be defined in the ordinary way and is

$$\frac{\phi(\mu)d\mu\,.f(x_1-\mu)\ldots f(x_n-\mu)}{\int_{-\infty}^{+\infty}\phi(\mu)d\mu\,.f(x_1-\mu)\ldots f(x_n-\mu)}. \tag{3}$$

In actual practice, of course, the function ϕ, which may be called the *a priori* probability function, is usually unknown. If we assume it to be constant, this expression reduces to (2), which shows that the use of the inverse statement, or the use of the Principle of Inverse Probability as it has been called, is equivalent to assuming all values of μ equally probable beforehand. This is clearly an unwarranted assumption. If there are many observations, the function (3) has a sharp peak for some value of μ, and provided $\phi(\mu)$ is fairly flat in this region, its actual form does not affect the result much. As n is increased the form of ϕ becomes immaterial, but it is nevertheless undesirable to introduce the function ϕ, since the whole of our knowledge is contained in the expression (1). R. A. Fisher (2) has called this function, without the $dx_1, dx_2, \ldots, dx_n$, the "*likelihood*" of μ having a given value, as distinct from the probability that the mean value lies between $\mu \quad d\mu$ 2. It is not a probability, and does not obey the laws of probability, but may nevertheless be postulated as a numerical measure of rational belief. By choosing μ so that the expression for the likelihood is a maximum, we get a value for the mean, say μ_0, and the chief property of the likelihood function is that the μ_0 so obtained is the most efficient estimate of the true mean. It can also be shown (1) that the variance of this estimate is given by

$$\frac{1}{\sigma^2} = -\frac{1}{n}\frac{\partial^2}{\partial\mu^2}\log L, \tag{4}$$

where L is the likelihood function. As illustration we may apply this to the ordinary Gaussian law. If the observations are $x_1, x_2, \ldots, x_n$, then

$$L = \exp\left(-\frac{1}{2\sigma^2}\Sigma(x_r-\mu)^2\right),$$

$$\frac{\partial L}{\partial \mu} = 0 \quad \text{gives} \quad \Sigma(x_r-\mu) = 0,$$

showing that the arithmetic mean is the most efficient statistic. Also

$$-\frac{1}{n}\frac{\partial^2}{\partial \mu^2}\log L = \frac{1}{\sigma^2},$$

which verifies equation (4) in this case.

Summarising, we may say that certain methods of estimating a quantity are more efficient than others, in the sense that the same accuracy can be obtained from fewer observations. The "method of maximum likelihood" allows us to choose the most efficient statistic, provided that we know the distribution of the quantity.

In combining observations the Gaussian law has almost always been assumed, but from the point of view of the general theory of statistics there is no particular reason why any population should have this special distribution. In the particular case of errors of observation, reasons have been given to show that the distributions should be Gaussian. According to Jeffreys (3) (and others) such proofs involve "a number of approximations, and when these are examined it is found that the law should hold only up to a moderate multiple of the standard error." We do find that series of observations which have been made under identical conditions, *as far as the observer is aware*, do not in general yield residuals following a Gaussian curve. Instead they often give an excess of small and large errors with a deficiency of intermediate ones. This would, indeed, be expected (4) if the population consisted of the sum of two or more Gaussian distributions with different variances, such as might arise from different observers or from variable conditions of measurement. It would be begging the question, however, to say that such deviations from the Gaussian distribution must always arise from some non-uniformity not detected by the observer, for this would be equivalent to *defining* a uniform series of observations as one where the residuals obey the Gaussian law. We cannot, in fact, either prove or disprove the usual presuppositions of the law by experiment. Nevertheless, errors of observation usually come reasonably near to obeying the Gaussian law, and this, combined with its simplicity of form and use, have led to its universal adoption. The arithmetic mean is then the best statistic, but should be used with caution : we may take the arithmetic mean of the values obtained for the parallax of a star since the parallax is actually observed, but the corresponding distances would not follow a Gaussian distribution. In many problems in stellar statistics Gaussian distributions for the velocities, densities, etc., are often assumed. Here there is no question of errors of observation, and in most cases the reason for using the Gaussian law is to be found entirely in the mathematical simplicity of the resulting analysis.

Summing up, we may say that the normal or Gaussian distribution is unquestionably the simplest to work with, and indeed in anything more

complex than a straight mean it is the only practicable one. It fits the facts reasonably well in the case of the residuals of a homogeneous series of observations. We shall therefore develop its properties at greater length.

Sampling Distributions.—We have already seen that the arithmetic mean of a sample is in general different from the mean of the whole population, and curve *A* of fig. 1 shows the relative frequency with which samples occur with means lying in any small region, the size of the sample being fixed. We shall call this the "sampling distribution" of the A.M. The idea of a sampling distribution is of fundamental importance. One instance of its use has already been mentioned; we saw that the sampling distribution of the median (*B*, fig. 1) was a flatter curve than that of the A.M., and were able to conclude that the median was not so efficient a statistic to use for the estimation of the mean of the whole population.

For the discussion of the significance of results obtained by the combination of observations it is necessary to develop the idea of sampling distributions, and we shall do this on the assumption that the observations follow a Gaussian curve. The sampling distribution of any quantity may be found; for example, the A.M., the standard deviation, the ratio of these two, the difference between the two extreme observations of the sample, and so on. To start with we shall consider the first two, the A.M. and the standard deviation. Let the population of errors be given by

$$ydx = \frac{1}{\sigma\sqrt{(2\pi)}} \exp\left(-(x-\mu)^2/2\sigma^2\right),$$

where the mean value is μ, and σ^2 is the mean square deviation or variance. Consider now a sample of n observations $x_1, x_2, \ldots, x_n$, and let us define a quantity $s^2 = \Sigma(x_r - \bar{x})^2/(n-1)$. The reason for introducing $n-1$ instead of n will appear later. Then the sample is characterised by two quantities, s^2 and $u = \bar{x} - \mu$, the distance of the mean of the sample from that of the whole population. The expression for the relative frequency of samples having s^2 and u within the limits $s^2 \pm ds^2/2$ and $u \pm du/2$ was originally given by Helmert (5) and is

$$ydud(s^2) = \left[\frac{\sqrt{n}}{\sigma\sqrt{(2\pi)}} e^{-\frac{nu^2}{2\sigma^2}} du\right]\left[\frac{(n-1)^{\frac{1}{2}(n-1)}}{2^{\frac{1}{2}(n-1)}\Gamma\left(\frac{n-1}{2}\right)} (s^2/\sigma^2)^{\frac{1}{2}(n-3)} e^{-\frac{1}{2}(n-1)s^2/\sigma^2} d(s^2/\sigma^2)\right]. \quad (5)$$

The first thing to notice is that s^2 and u are distributed independently of each other. This is perhaps surprising, as we might have expected a sample with a large variance to be more likely to have a large value of u. (We must remember that σ^2 is fixed; if this were not so, a large value of s^2 would indicate a large σ^2 and this in turn a large average value of u.) If we integrate over all values of s^2 we are left with the first bracket only, which shows that u follows a normal curve with variance σ^2/n. From this follows the well-known result that the probable error of the mean of n observations is $\rho/\sqrt{n}$, where ρ * equals $0{\cdot}6745\sigma$ and is the "probable error" of a single observation.

* We use Greek letters (ρ, σ, μ) for the parameters of the population, and Roman ones (r, s, m) for the sample.

Again, if we are interested only in the distribution of s^2, we must integrate over all values of u and we are left with the second bracket, giving the distribution of the variance of the sample as a function of n and s^2/σ^2 (or s/σ). The distribution curves are skew, but as n increases they tend to become normal and symmetrical about the point $s = \sigma$. For large n the distribution curve for s is approximately normal with standard deviation $\simeq \sigma/\sqrt{(2n)}$. This leads to the (less precise) statement that

$$\frac{\text{P.E. of } r}{\rho} = \frac{\text{P.E. of } s}{\sigma} = \cdot 6745 \frac{\text{M.S.E. of } s}{\sigma} \simeq \frac{\cdot 6745}{\sqrt{(2n)}},$$

when n is large, which is the approximate formula for the probable error of the probable error.

The fundamental problem of estimation is to say something about μ and σ^2 from a knowledge of $\bar{x}$ and s^2, which is all we have from experiment. As regards μ, the obvious course is to take $\bar{x}$ as the best available value, its mean square deviation being σ^2/n. The "best" value of σ^2 is somewhat more arbitrary ; it is usual to choose s^2, since $\overline{s^2}$, the average over all samples, is in fact equal to σ^2. This is equivalent to equating the observed s^2 to the mean value of the distribution curve of s^2, but we might have taken the median or mode instead, or some value from the distribution curve of s, and obtained a different estimate. The equation $\overline{s^2} = \sigma^2$ supplies the reason for the definition of s^2 with $n - 1$ in the denominator instead of n. We shall call s^2 the estimated variance of the population. It is interesting to note that this estimate of σ^2 is also obtained by applying the method of maximum likelihood to the second bracket of (5), so that of all the populations with different values of σ^2, that with $\sigma^2 = s^2$ is the most likely to give a sample with $s^2 = \Sigma(x_r - \bar{x})^2/(n-1)$.

It is usually stated that σ^2 *equals* s^2, but we should always bear in mind that this is only an estimate of σ^2 and, moreover, one of many possible estimates. This being so, it is essential to realise that in giving the P.E. of a set of results we are really only giving an estimate of the P.E., and it is therefore very desirable to give some idea of the reliability of this estimate. The number of observations on which it is based should always be given in preference to the so-called "probable error of the probable error." The reason for this will appear when we come to consider the tests of significance which we can apply to our results. In combining different sets of observations it is usual to assign weights $\sim 1/s^2$, but we must beware of overweighting sets of observations with a fortuitously small value of s^2. For example, in the determination of the parallaxes of 251 stars at Greenwich, the estimated probable errors ($\cdot 6745s$) of plates of unit weight vary between $''\cdot 013$ and $''\cdot 041$. But the spread is not much greater than that which we should expect in samples taken from a population of constant σ. It is therefore preferable in this case to adopt a constant probable error for all the stars.

Problems of "Significance."—We can now discuss the second type of problem, which is concerned with the significance of the results we may have

obtained, and has considerable bearing on the detection of systematic errors. A typical example may be enunciated as follows :—Suppose we have n observations $x_1, x_2, \ldots, x_n$, the mean being $\bar{x}$ and the estimated variance s^2, whereas from previous measurements we have reason to suppose that the value of the quantity is really x_0. How shall we decide whether the difference $\bar{x} - x_0 (= u)$ is due to a systematic error of the later measurements or due to the chance distribution of the sample taken? Certainty is, of course, impossible, but some objective statements of probability can be made. Let us firstly assume a Gaussian distribution and a definite value of σ.

The sampling distribution of u is given by the first bracket of expression (5), which represents a normal curve with standard deviation $\sigma/\sqrt{n}$ and is shown in fig. 2.

If we shade off two equal areas at the ends whose sum is equal to $1/p$ of the total area, then there is only one chance in p that the mean of a sample

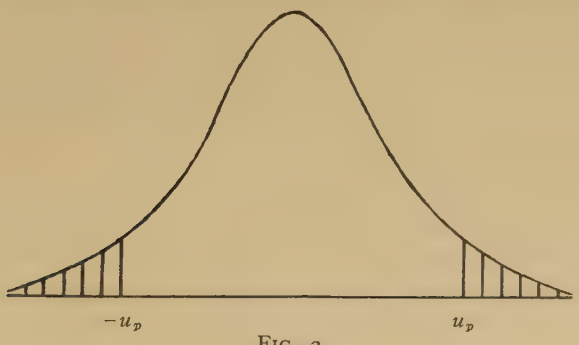

FIG. 2.

will fall in the shaded area. The value of u_p at which the shading starts is given by

$$\int_{u_p}^{\infty} e^{-nu^2/2\sigma^2} du \Big/ \int_{0}^{\infty} e^{-nu^2/2\sigma^2} du = 1/p. \qquad (6)$$

Taking, for example, $p = 20$, then with $\sigma/\sqrt{n} = 1$ we find $u_p = \pm 1{\cdot}96$, so that we expect to find only one sample in 20 for which $|u| > 1{\cdot}96$. If the mean $\bar{x}$ of our observations differs from the suggested value x_0 by a quantity greater than 1·96, we may decide that it is not a chance observation (since such would occur only once in 20 times) and accordingly attribute it to a real or systematic difference. The critical value of p is of course arbitrary, and some prefer to use $p = 100$. These two values of the probability (·05 and ·01) are frequently used and are called the 5 per cent. and 1 per cent. significance levels respectively. The values of $u\sqrt{n}/\sigma$, the variable in the integrals (6), have been calculated for different values of p (6).

It is of interest to examine the logical content of the above statements and the deductions which can be drawn from them. So far we have shown that *if* x_0 is the true value of the mean, then there is one chance in 20 that the sample will have a mean $\bar{x}$ such that $|x_0 - \bar{x}| > 1{\cdot}96$. On the other hand, if we wish to say that, having found $\bar{x}$ but knowing nothing about x_0,

there is only one chance in 20 that x_0 is such that $|\bar{x}-x_0| > 1{\cdot}96$, then we must be very careful about the meaning of the latter statement. It must not be interpreted as a probability, *in the sense of expression* (3), that $|\bar{x}-x_0| > 1{\cdot}96$, since this would be an appeal to the so-called principle of inverse probability and would imply that all values of x were *a priori* equally probable. We can, however, make an objective statement of probability of a rather different kind which has been called "fiducial probability" by Fisher (2) to distinguish it from the probability defined in the sense of expression (3). We may say that if, during the course of various investigations, we have occasion to examine a number of samples (with $\sigma/\sqrt{n}=1$), only in one in 20 examples should we expect to find $|\bar{x}-x_0| > 1{\cdot}96$. Hence if we are prepared to make one wrong deduction in every 20 we may say that $|\bar{x}-x_0| < 1{\cdot}96$. Alternatively we may say that the (fiducial) probability that $|\bar{x}-x_0| > 1{\cdot}96$ is 1/20, meaning nothing more or less than that there is one chance in 20 of being wrong when we assert the contrary. The logical content of the two statements, of inverse and fiducial probability, is quite different. The probabilities differ in referring to different populations: "that of the fiducial probability is the population of all possible random samples; that of the inverse probability is a group of samples selected to resemble that actually observed" (7).

The significance test just discussed suffers from the disadvantage that we have to know the value of σ. In general, we can only make an estimate of it from the sample itself. There are other tests of significance which do not suffer from this disadvantage, although the logical content of all such tests must necessarily be of the type discussed. One in particular may be mentioned. We have seen that the usual estimate of σ^2 is given by s^2 or $\Sigma(\bar{x}-x_r)^2/(n-1)$, so that the estimated standard deviation of the mean of the sample is

$$\frac{s}{\sqrt{n}}=\sqrt{\left(\frac{\Sigma(\bar{x}-x_r)^2}{n(n-1)}\right)}.$$

We define the quantity t by

$$t=\frac{\bar{x}-\mu}{s/\sqrt{n}},$$

which is the distance of the mean of the sample from the mean of the population in units of the estimated standard deviation of the population, which is known. It can be shown (8) that the sampling distribution of t is given by

$$ydt=\frac{\text{const.}\ dt}{(1+t^2/\nu)^{\frac{\nu+1}{2}}}, \tag{7}$$

with $\nu=n-1$. This is not a normal curve, but for large n it tends to $e^{-\frac{t^2}{2}}$, a normal curve with unit standard deviation. The significance of a result is tested as before; an example may illustrate this best. Suppose we have five observations of a quantity x such that $\bar{x}=3$, $\sqrt{\left(\frac{\Sigma(\bar{x}-x_r)}{n(n-1)}\right)}=2$, so that the

result would be written $x = 3 \pm 1{\cdot}359$ (P.E. $= \sigma \times {\cdot}6745$) in ordinary astronomical notation. Let us test the hypothesis that the true value $x_0 < 0$; we then have $\bar{x} - x_0 > 3$, so that we must take $t = 3/2$. We find from the appropriate tables (9) that the ordinate at $t = 3/2$ cuts off a fraction 0·104 of the *total* area under the curve (7), so that there is about one chance in ten that we should find a sample with $\bar{x} > 3$ (algebraically). We might therefore say that the true value of x is greater than zero, with the knowledge that we shall be wrong once in every ten times that we make such a decision. It is interesting to consider the same data, viz. $x = 3 \pm 1{\cdot}359$, when $n = 100$. (The P.E. of a single observation is much greater now.) We find that the ordinate $t = 3/2$ cuts off 0·067 of the total curve, so that when we say the true value of x is greater than zero we shall now be wrong about once in fifteen times. This example shows that the probable error is not in itself sufficient to test the significance of a result, and we would emphasise again that the number of observations should always be included. The t test just described does not require a knowledge of σ, but it must be pointed out that if the sample happens to have a fortuitously large or small value of s^2, then the results may be misleading.

It often happens that we have two sets of observations, $x_1, x_2, \ldots, x_n$ and $x_1', x_2', \ldots, x_m'$, with means $\bar{x}$ and $\bar{x}'$, and we wish to see if the difference $|\bar{x} - \bar{x}'|$ may be considered as having arisen from chance variations. Here we find the sampling distribution of $\bar{x} - \bar{x}'$ and apply similar arguments to those discussed above. Actually it is better to use a quantity corresponding to the t of the last test:

$$t = \frac{\bar{x} - \bar{x}'}{\sigma} \sqrt{\left(\frac{nm}{n+m}\right)},$$

where

$$\sigma^2 = \frac{1}{n+m-2}\{\Sigma(\bar{x} - x_r)^2 + \Sigma(\bar{x}' - x_r')^2\}.$$

The sampling distribution of t is then given by equation (7) with $n+m-2$ replacing ν, and as before we find the chances of as large a value of $|t|$ turning up. In practice it is sometimes most convenient to tabulate only those values of t corresponding to the 5 per cent. and 1 per cent. significance levels, as an accurate evaluation of the chances of taking a wrong decision is not essential. Some care is necessary when referring to the tables of the t test. For a given (positive) value of t, some tables give the fraction of the area of the *whole* lying to the right of the ordinate, while others give the fraction lying outside the ordinates $\pm t$, which is just twice as great. In the example worked out the former will give us the (fiducial) probability that $\bar{x} - x_0 > 3$, and the latter the probability that $|\bar{x} - x_0| > 3$. Which we require depends on the hypothesis we are testing; for the difference of two means we use $|\bar{x} - \bar{x}'|$.

Finally, we would mention the distribution of the correlation coefficient in samples chosen from a normal population where there is really no correlation. If r is the correlation coefficient in a sample of n, we find the

corresponding value of t, defined by

$$t = \frac{r}{\sqrt{(1-r^2)}}\sqrt{(n-2)}.$$

It may then be shown that t is distributed according to equation (7) with $\nu = n-2$. Thus for the example mentioned at the beginning of the report, we have $r = 0{\cdot}4$, $n-2 = 8$, $t = 1{\cdot}23$, and we find that about once in every 4 samples the value of $|r|$ will exceed 0·4. Thus the correlation coefficient cannot be said to be significant in this case. From these examples it will be seen that the t test is of great generality. Its importance arises from the fact that we do not need to assume a value for σ.

Summing up, we may say that we cannot in general state the probability that the mean or some parameter of a population lies within certain limits. On the other hand, if we care to make an assertion of the type that the mean of the population is always within a certain distance of the mean of the sample, then we can choose this distance so that, on an average, we shall only be wrong once in a stipulated number of times. Of course, if we know something about the function $\phi(\mu)$, the *a priori* probability, then we can make definite statements of probability of the first type (expression (3)). This, however, is not often the case.

The χ^2 Test of Significance.—This is a test of very general use which was developed by Karl Pearson (10). Its application is best understood by an example :—In estimating the reading of a scale to a tenth of a division, it is well known that certain observers have a bias towards some values; 0·0 and 0·5, for example, often occur much more frequently than would be expected. Let us consider the following (imaginary) data :—

Tenth . .	0·0	0·1	0·2	0·3	0·4	0·5	0·6	0·7	0·8	0·9	
Number of Observations .	102	118	89	94	85	121	91	105	83	112	Total 1000

We have to decide if the observer really has a bias towards certain values, or whether the variations are probably due to chance. This type of problem is frequently encountered ; we have a number of cells into which the events fall, together with a hypothesis about the relative number expected in each cell. Here we shall first test the hypothesis that the deviations from uniformity are due to chance. The quantity which is used is defined by

$$\chi^2 = \sum_n \frac{(m_r - \bar{m}_r)^2}{\bar{m}_r},$$

where m_r is the number of events falling in the rth cell, $\bar{m}_r$ the number expected on the given hypothesis and n the number of cells. It can then be shown that if the $\bar{m}_r$'s are not too small, the sampling distribution of χ^2 is given by the curve

$$y = \text{const}\ e^{-\chi^2/2}\chi^{\nu-1}. \qquad (8)$$

The number ν is called the number of degrees of freedom of the aggregate of cells, and is equal to the number of cell frequencies which may be assigned

at will. It is therefore equal to $n-\kappa$, where κ is the number of independent linear relations or constraints in the data. Here there is only one; that the sum of the actual frequencies is equal to the sum of the expected ones. Hence $\nu=n-1=9$.

In the example given, assuming $\bar{m}_r=100$, we find $\chi^2=16{\cdot}9$, and looking up the appropriate table (9) with $\nu=9$ we find

$$P(\chi^2)=P(16{\cdot}9)=\text{area of curve to the right of the ordinate}=0{\cdot}05.$$

Hence there is about one chance in 20 of obtaining so great a value of χ^2 due to chance deviations from uniformity. We therefore conclude that the deviations are real. From the data we see that Σ (odd tenths) $=558$ and Σ (even tenths) $=442$, which suggests that we might test the hypothesis that the chance of an odd tenth being read is 0·56 and an even tenth 0·44. Putting in the new values of $\bar{m}_r$ we now find $\chi^2=7{\cdot}3$. We have now imposed two constraints on the cell frequencies, so that $\nu=8$. This gives us $P(7{\cdot}3)=0{\cdot}5$, so that deviations as great or greater than those actually observed are quite usual, and this test does not offer any grounds for rejecting the second hypothesis.

The additive property of χ^2 is very useful. If we have two sets of similar data with χ_1^2, ν_1 and χ_2^2, ν_2 (ν_1 will usually be equal to ν_2), it is easy to show that we may use the whole of the data to test a given hypothesis by putting $\chi^2=\chi_1^2+\chi_2^2$ and $\nu=\nu_1+\nu_2$.

The χ^2 test may also be used when the variables are continuous (11). If we have ν independent variables $x_1, x_2, \ldots x_\nu$, with normal distributions about zero, of variances $\sigma_1^2, \sigma_2^2 \ldots, \sigma_\nu^2$, then putting

$$\chi^2=\sum_r \frac{x_r^2}{\sigma_r^2},$$

we may show that the sampling distribution of χ^2 is again given by (8).

In conclusion I should like to thank Dr. J. Wishart for the opportunity of discussing with him the subject-matter of this report.

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REFERENCES

(1) R. A. Fisher, *Proc. Cam. Phil. Soc.*, **22**, 706, 1925. This paper deals with the idea of "efficiency."

(2) R. A. Fisher, *Proc. Cam. Phil. Soc.*, **26**, 528, 1930, and *Proc. Roy. Soc.*, A, **139**, 343, 1933. See also H. Jeffreys, *Theory of Probability*, for the opposite point of view, in particular the first chapter.

(3) H. Jeffreys, *Phil. Trans. Roy. Soc.*, A, **237**, 231, 1938.

(4) A. S. Eddington, *Proc. Phys. Soc.*, **45**, 271, 1933.

(5) A fuller account of the distribution of samples and of significance tests is given in a very useful article by Deming and Birge in *Reviews of Modern Physics*, **6**, No. 3, 1934. References to Helmert's paper and many others are given here.

(6) E.g. *Trans. Roy. Soc. Edin.*, 39, pt. ii, 257–322, or almost any book on statistics or statistical tables.

(7) *Proc. Roy. Soc.*, A, 139, 348, 1933.

(8) This distribution, called "Student's" distribution, is given in most books on statistics; for example, *Statistical Mathematics*, by A. C. Aitken.

(9) *E.g.* Fisher and Yates, *Statistical Tables*, or reference (10).

(10) An excellent account of the χ^2 test is given in Yule and Kendall's *Introduction to the Theory of Statistics*.

(11) *E.g.* Jeffreys' *Theory of Probability*, § 2.7.

In the above we have tried to give references accessible and useful to the astronomer, and the original papers on the subject are therefore not necessarily given.

METEORS

1. *Introduction.*—There can hardly be found another branch of astronomy where the mere accumulation of observational data has so small an influence upon the progress of our knowledge as it has in meteor research. If there has been a noticeable progress in the science of meteors during recent years, it is chiefly due to the application of special methods of reduction and discussion, and to the arrangement of specially planned observations. The chief difficulty consists in the fact that in visual observations the observer has to rely upon his memory, which is apt to transform the original impression into a record that may considerably differ from the "ideal" one; the impossibility of the same observer checking his observation adds to the difficulty. Even such semi-instrumental methods as the rocking-mirror observations of meteor velocities are by no means free from the above difficulty. In view of these facts, the study of observational errors plays a much more important rôle in the discussion of meteor observations than anywhere else; duplicate simultaneous observations by two or more persons are a prerequisite for a successful study of the observational errors. In statistical studies on meteors, the problem of freeing an observed frequency table from the effect of observational error dispersion becomes of primary importance and, in view of the ordinarily large error dispersion, requires special methods of treatment. From all these considerations the importance of accurate photographic observations cannot be overestimated; in spite of scarce statistical material, depending upon the actual sensitiveness of photographic plates, photographic observations may yield a valuable check upon the results deduced from visual observations; in other respects, such as the study of meteor spectra, the photographic plate yields results which are unrivalled.

2. *Observational Activity.*—The Arizona Expedition for the Study of Meteors (1931–33) * was a conspicuous enterprise in meteor research during recent years; the purpose of the expedition was to obtain a general view of the meteor world, without too much attention to detailed results: the general distribution of velocities, directions of motion, heights, group radiants, magnitudes. About one-half of the results have already appeared †, referring to velocities, radiants and heights. The discussion of the distribution of the directions of motion, of the frequency of absolute magnitudes, and other related problems awaits completion.

During recent years Hoffmeister has arranged special observations (counts) for the determination of the diurnal and seasonal variation of meteor numbers in different latitudes. Valuable data are being accumulated by McIntosh in New Zealand; his observations, made according to a routine programme, fill out the gap which has hitherto existed in respect

* *Proc. Nat. Acad.*, **18**, 16, 1932.

† *H.C.*, Nos. 388–391, 1934; *H.A.*, **105**, 549, 1937; also *Tartu Obs. Publ.*, **30**, No. 5 (in press).

to meteor frequencies, diurnal and annual variation, and radiants in the southern hemisphere.

The American Meteor Society, under the direction of C. P. Olivier, continues the accumulation of huge numbers of routine observations, with meteor frequencies and radiants as the chief purpose. Similarly, large numbers of observations are obtained by individual and co-operative workers in Soviet Russia ; their programme often differs in several respects from the ordinary routine programme. Other special visual and photographic observations are mentioned below in connection with the corresponding subsections.

3. *The Variation of Meteor Frequency.*—On the assumption of a uniform distribution of the heliocentric direction of meteors, Hoffmeister gave a mathematical expression for the meteor frequency as a function of the zenith distance of the orbital apex of the Earth, with the mean heliocentric velocity c as parameter * ; from his own observations of the diurnal variation, as well as from different old and recent observational series, Hoffmeister finds for sporadic meteors values of c from 2 to 3, about 2·5 on the average, the orbital velocity of the Earth being taken as the unit. The values are considerably in excess of $\sqrt{2}$, the parabolic limit, and thus seem to indicate an extra-solar origin for the majority of sporadic meteors. For the southern hemisphere, McIntosh derives, from 13,000 observations, a mean diurnal variation which leads to $c = 3{\cdot}0$.† Astapovič finds from a limited series of 1594 observations a minimum value of $c = 1{\cdot}68$.‡ These results are not in contradiction with Hoffmeister's main result.

Öpik objected to Hoffmeister's method §, pointing out that the assumption of the luminosity being independent of velocity is probably unsound, whereas the assumption of a uniform distribution of the heliocentric directions is arbitrary. The same critical points are stressed by Hoppe. ‖ It appears that the parameter c, representing a definite characteristic of the curve of variation of meteor frequency, is not related in a simple manner to the mean heliocentric velocity of meteors ; it includes unknown influences, in the first place possible preferential directions of motion.

In recent publications Hoffmeister practically admits the validity of these criticisms ; thus, he calls the values of c found from the variation data "apparent effective velocities" ; the annual variation of c as well as the increase of c toward southern latitudes of the observing station Hoffmeister considers now as an apparent phenomenon, depending upon preferential motion. ¶ Nevertheless, he points out that his general mean of c agrees well enough with direct velocity determinations by Öpik, which

* *Erg. H.A.N.*, **4**, No. 5, 1922 ; *Veröff Berlin-Babelsberg*, **9**, No. 1, 1931 ; also cf. *Die Meteore*, Leipzig, 1937.

† *Popular Astronomy*, **46**, No. 9, 1938.

‡ *C.R. de l'Acad. de Sci. de l'U.R.S.S.*, 1934 September 21.

§ *H.C.*, No. 355, 1930, and earlier papers. ‖ *A.N.*, **264**, 233, 1937.

¶ *Mitteilungen Sonneberg*, No. 33, 1939 ; *Die Meteore* ; *Sitzungsber. preuss. Akad. Phys.-Math.*, **18**, 1936.

perhaps indicates that the interpretation of c as a certain mean velocity is not absolutely misleading.

On the other hand, from an analysis of the direction of motion of 1436 meteors with velocities observed in Arizona, Öpik finds an unexpectedly large number of meteors moving from the antapex * ; the data are of such a character that Öpik revises his former views regarding the dependence of luminosity upon velocity ; instead of the cube law, the actual dependence of meteor luminosity upon velocity may require as low a power of velocity as $s = 1{\cdot}3$ (the figure is uncertain, however), thus much closer to Hoffmeister's and Schiaparelli's model ($s = 0$). In spite of the fact that laboratory experiments with canal rays indicate for the luminous efficiency of a moving atom (of an unchanged degree of ionization) about $s = 3$, in agreement with Öpik's former theory, a lower value in meteors may result through the increasing average state of ionization with increasing velocity, in connection with the lower luminous efficiency of highly ionized meteor atoms, as compared with the neutral state and the lower states of ionization.

Integrated meteor counts, in which the distribution of directions (and velocities) is left out of consideration, represent an observational material poor in details ; the derivation of the different characteristics of the meteor world from these meagre data alone appears to be a rather thankless task : the number of unknowns is large, the number of equations is small and their coefficients are often nearly proportional. The difficulties encountered in the attempt of finding but one parameter, the mean heliocentric velocity, are described above. Despite these difficulties, Hoffmeister thinks himself able to read off more detail from his data referring to the diurnal, annual and geographical latitude variation of meteor numbers ; he finds certain preferential directions of motion, from the constellations of Taurus (chief direction, $\alpha = 50°$, $\delta = 20°$) and Scorpius †, which he identifies with certain preferential directions found among fireballs by v. Niessl and Knopff. Hoffmeister ascribes these to a phenomenon of the nature of star-streaming among interstellar meteors. Noticeable is the absence of the effect of solar motion in Hoffmeister's meteor-streaming. Recently Hoffmeister remarks that this streaming is severely obscured by cometary radiation, namely from Scorpius in May (observations in the southern hemisphere), from Taurus in October–December, and that the space-density of these interstellar stream-meteors may be so small that it would be difficult to observe directly radiants from these streams within a few hours or days.‡ Certain dynamical difficulties, involved in Hoffmeister's conceptions of a phenomenon of meteor-streaming, which does not coincide with the star-streaming of our stellar universe, are considered by Hoppe.§

4. *Velocities.*—A most remarkable paper on meteor velocities is published by F. L. Whipple ‖ ; it refers to Harvard rotating-shutter photographs

* *Tartu Obs. Publ.*, **30**, No. 5 (in press).
† *A.N.*, **243**, 213, 1931, and later publications (*loc. cit.*).
‡ *Mitteil. Sonneberg*, No. 33, 1939. § *A.N.*, **264**, 337, 1938.
‖ *Proc. Am. Phil. Soc.*, **79**, 499, 1938 ; *H.R.*, No. 152.

of six meteors, for which accurate heights are available from duplicate photographs. The time of appearance is directly observed only in one case, whereas for the rest the assumed time depends upon the identification of details on the two trails and may be uncertain in two cases. The heliocentric velocities, reasonably corrected for deceleration, are (in km./sec.): 36·3, 34·5 (Geminid); 37·4, 51·9, 38·8, 41·4 (Perseid). Thus, the Geminid reveals a short-period elliptical orbit, $a = 1{\cdot}46$, $e = 0{\cdot}905$, $P = 1{\cdot}76$ years; the Perseid yields $P = 110$ years, fairly close to what has been formerly estimated for this stream. Three sporadic meteors have elliptical orbits, of an "asteroidal" character, with small inclination and direct motion, of periods 2·6, 3·3 and 5·7 years respectively, whereas one reveals retrograde motion with a moderate hyperbolic velocity. Whipple questions the reality of the latter and changes arbitrarily the time of apparition, in order to obtain an elliptical velocity which he thinks must be assumed on the basis of the physical theory of meteor phenomena. Öpik reconsiders the question *, and finds that Whipple's original hyperbolic value of the velocity is alone compatible with the physical theory too. Even if so, the proportion of hyperbolic velocities seems to be considerably smaller among photographed (*i.e.* very bright) meteors than found from visual observations (faint objects).

Whipple measures directly the deceleration along the meteor trail and finds for it relatively small but well-determined values; the loss in velocity amounts to 0·5 per cent. for the fastest ($v = 80$ km./sec.) to 8 per cent. for the slowest meteor ($v = 13$ km./sec.), in qualitative and approximate quantitative agreement with prevailing physical theories. Whipple's data disprove the large values of deceleration found by Millman and Hoffleit † with the aid of hypothetical heights; their failure is chiefly explained by the use of Öpik's ‡ mean heights of sporadic meteors in the case of their shower meteors; with the actual mean heights of the shower meteors the spurious decelerations disappear.

Olivier published twenty velocities derived from Elkin's photographs § (only four sporadic meteors, the rest belonging to showers); for various reasons explained by the author the accuracy of this series is unsatisfactory, being comparable to the accuracy obtainable in visual observations of velocity.

Results of rocking-mirror visual observations of meteor velocities are discussed by Öpik ‖; the last publication refers to 1436 velocities observed in Arizona (1931–33) by three observers, including the author. In the rocking-mirror device, the reflection of the meteor trail is observed from a mirror which follows a conical vibration; the period was $0^{s}{\cdot}1$ in the present case. The number of waves and their apparent shape in the resulting cycloid furnish the basis for the determination of angular velocity. The meteor trails were traced on star-maps with reference to constellations, thus being unlike the reticle method of the rest of the Arizona observations;

* *Tartu Obs. Publ.*, **30**, No. 5 (in press).
† *H.A.*, **105**, 601, 1937.
‡ *H.A.*, **105**, 549, 1937.
§ *A.J.*, **46**, 41, 1937.
‖ *H.C.*, Nos. 389 and 391, 1934; *Tartu Obs. Publ.*, **30**, No. 5 (in press).

all observations refer to the north polar region. Systematic and accidental errors are involved, which are partly in the length of the trail and partly in the number and shape of the waves. Mean heights were used, because the cosmic spread in meteor heights was smaller than the observational error in the observed heights depending upon the comparatively small base-line of the Arizona Expedition. The errors of observation were studied from a comparison of the observed and theoretical velocities of shower meteors, for which the velocities were computed on the assumption of near parabolic orbits.* The accidental error in the logarithm of velocity was found to be $\pm 0{\cdot}106$ (p.e.), or about ± 25 per cent. Unpublished rocking-mirror observations by Öpik (1934–38) made at Tartu with reference to reticles instead of stars, and in which only the number of waves was determined, no attention being paid to the shape of the trajectory (the eye partially follows slow meteors and distorts the shape of their cycloids, whereas the number of waves remains unaffected), yielded a considerably greater accuracy, of about $\pm$ 10 per cent.

The data were freed from the effect of observational error dispersion and were analysed separately in twelve groups of direction (relative to the apex). One of the main results is tabulated below (notice $v = 42{\cdot}1$, the parabolic limit).

Distribution of Heliocentric Velocities of 1436 Naked-eye Meteors

(All Directions)

Velocity, km./sec.	12·5	14·9	17·7	21·1	25·1	29·8	35·4	42·1	50·1	59·6
Percentage	1·1	0·6	0·2	2·5	3·1	9·6	16·8	19·4	15·6	

Velocity, km./sec.	59·6	70·9	84·3	100·2	119·2	141·7	168·5	200·5	238·3	283·3	Sum
Percentage	11·7	9·8	5·7	2·1	0·3	0·4	0·5	0·5	0·1		100·0

The distribution of space velocities was derived with the aid of semi-empirical frequencies of the ratios (tangential/space velocity), established separately for each sector of apical direction of motion. There is considerably less of a hypothetical element involved in the procedure, and the data contain more detail than in Öpik's preliminary results.† It is interesting to notice that about 7 per cent. seem to have velocities smaller than the orbital velocity of the Earth, more frequently of direct motion, and may be classified as "zodiacal light" meteors, of the same kind as some peculiar fireballs considered by Hoffmeister.‡

Boothroyd obtained in Arizona a number of telescopic meteor velocities with a conical motion-mirror device and a 4-inch telescope §; these telescopic observations revealed an unusually large percentage of high hyperbolic velocities. However, check observations arranged at Harvard by Öpik and F. Watson (a total of seven nights in 1933 by both observers) failed to

* A correction for the probable ellipticity of the orbits of meteor showers was introduced in the final data.

† *H.C.*, No. 391, 1934.

‡ *Popular Astronomy*, January 1937.

§ *H.C.*, No. 390, 1934.

reveal the high velocity excess; the instrument was the same as used by Boothroyd, whereas the policy was to avoid doubtful objects. Although the number of Öpik and Watson's observations (unpublished) is small, it is sufficient to show the discrepancy:

Projected Heliocentric Velocity, km./sec. (uncorrected)	0–21	21–42	42–84	⩾ 85	All
Number, Boothroyd, 1931–32, telescopic	44	133	178	225	580
Number, Ö. and W., 1933, ,,	6	15	9	0	30
Number, Ö., 1931, naked-eye	25	104	107	43	279

Doubtless the matter needs to be considered carefully.

5. *Radiants and Showers.*—The reality of "group radiants" is the current problem. It is probable that a large fraction of radiants in various published lists are not real. Maltzev arranged experiments which demonstrated how easily accidental radiants can be formed.* Öpik developed a method of calculating the probabilities of reality of group radiants and applied it to the Arizona data †; the probability of reality is determined from the observed frequency of the apparent errors in direction (position angle), as compared with the "ideal" direction from the adopted radiant; an additional criterion of reality follows from coincidences of radiants found on consecutive dates; the probable number of observed members of a radiant is obtained as a by-product. This latter, multiplied by the probability of reality of the radiant, gives the probable number of observed real members of a group radiant. In this manner it was found that 26 per cent. of all Arizona meteors in autumn, and 15 per cent. during the rest of the year, belong to detectable real group radiants. From 26,000 observations on 366 nights (combined into 239 units), a working list of 2000 radiants was compiled in a more or less usual manner; the probable number of real radiants in the list is found equal to 223 (this is equal to the sum of the probabilities of reality), or only 11 per cent. of the original list. Radiants with a probability of reality exceeding 0·20 are published individually; in spite of such a low limit of probability the list contains only 279 items. In reply to some doubts expressed by Olivier ‡, Öpik explains his standpoint with respect to the routine radiant programme §; it appears to be possible to calculate the probability of reality in the case of already published lists of radiants if the original maps are available, and if no meteors were omitted by the observer on account of disagreement with an expected direction.

Tables and graphs for the determination of apparent radiants of hyperbolic meteors from the given extra-solar radiant and velocity, and *vice versa*, are published by S. Orlov. || Similar tables, prepared by F. L. Whipple, have been available at Harward in manuscript form since 1934. Tables for the computation of zenithal attraction are published by Nielsen. ¶ Maltzev ** and McIntosh †† propose to use accurate observations of zenithal attraction

* *A.N.*, **234**, 243, 1928.
† *H.C.*, No. 388, 1934.
‡ *Popular Astronomy*, June–July, 1938.
§ *Popular Astronomy*, April 1939.
|| *A.J. of Soviet Union*, **13**, 1936.
¶ *Medd. Ole. Römer Obs.*, No. 12, 1938.
** *Publ. Tashkent Obs.*, **4**, No. 2, 1933.
†† *M.N.*, **96**, 704, 1936.

for the determination of the velocities of meteor streams; however, no application of this method is yet known. The display of Giacobinids on 1933 October 9 has been widely observed and discussed. A remarkable discussion is due to Arend and Hunaerts *; it contains the reduction of a number of trails photographed by Delporte, with the derivation of a precise radiant calculated from the measures according to a special method devised by these authors; the cross-section of the shower is also studied on the basis of meteor counts. Astapovič published a note on the Giacobinids, which were expected at Stalinabad †; unfortunately clouds intervened at the most interesting moment; nevertheless, special observations could be arranged.

Another analytical method for the photographic determination of radiants is developed by Jagolim.‡

McIntosh published 845 radiants observed in New Zealand, together with meteor rates.§ Sytinskaja derives 827 radiants from over 16,000 observations obtained on 343 nights.‖ A great number of co-operative observations of Perseids have been obtained in Russia.

The fine structure of the Orionid meteor stream has been studied by Prentice¶; he thinks to be able to distinguish four components, separated from each other by as small a distance as 2° on the average; he supports also the former conclusion of Olivier that the radiants are not stationary, contrary to Denning's opinion.

6. *Spectra.*—The investigation of meteor spectra is given a solid basis through Millman's researches **; twenty-three meteor spectra are thoroughly analysed; the spectra are collected from all over the world, the majority being due to Harvard and branches; Millman continues the collection of meteor spectra and keeps a record of all spectra obtained on an international scale; by the end of 1937 his catalogue of meteor spectra contained forty-five items, the recent additions coming from the United States, Canada, Russia and Sweden. Millman identifies in the meteor spectra lines of elements which are known to be common in meteorites, proving thus the chemical similarity of the two classes of objects. Lines of neutral iron appear in all cases, those of ionized and neutral calcium in many; nickel, magnesium, manganese, chromium, probably also sodium, aluminium and silicon are found. Two principal classes of meteor spectra are distinguished: Type Y, showing the strong lines H and K of ionized calcium; and Type Z, where these lines are absent. The first class doubtless belongs to stone meteors, whereas the second need not necessarily be typical iron. Most, if not all, meteors belonging to the major showers, especially the Leonids, appear to belong to class Y. About two-thirds of the spectra of sporadic meteors are of

* *Bull. Acad. Royale de Belgique*, **20**, 538, 1934.

† *Bull. Observers' Corp. U.S.S.R.*, No. 42, 1937.

‡ *Bull. Observers' Corp. U.S.S.R.*, No. 41, 1936, and No. 43, 1937.

§ *Trans. N.Z. Inst.*, **60**, 448, 1929; **63**, 433, 1934; **66**, 60, 1936; also *M.N.*, **95**, 709, 1935.

‖ *Publ. Astr. Obs. Leningrad*, **7**, 73, 1936.

¶ *J.B.A.A.*, **43**, 376, 1933; **46**, 329, 1936; **49**, 148, 1939.

** *H.A.*, **82**, No. 6, 1932, and No. 7, 1935; also "Meteor News" in *J.R.A.S. Canada*.

class Z. Separate studies of single meteor spectra are published by Schalén and Wernberg *, and by Hopkins.†

7. *Photography.*—Two catalogues of meteors photographed at Harvard College Observatory have appeared: the first, by Fisher and Olmsted, containing 386 items ‡; the second, by Hoffleit, referring to 240 trails.§

The technique of meteor photography and spectrography and its expectation of success are considered by Millman.‖ Experiments referring to the efficiency of various types of lenses in meteor photography are carried through by Sytinskaja.¶ The relative frequency of photographic meteors in different zenith distances is studied theoretically by Millman **, and is found to depend upon the increment ratio of meteor numbers with magnitude, $N(m+1)/N(m)$; from the actual distribution of Harvard meteor photographs according to zenith distance Millman finds $N(m+1)/N(m) = 3{\cdot}5$ ††; this important result is supposed to define the frequency function of meteor luminosities roughly between magnitudes -2 and -7.

Hoffleit published a study of the relative distribution of brightness along meteor trails ‡‡; meteor trails are classified according to the position of maximum light. Sytinskaja develops a method of absolute photographic photometry of meteors by comparing the meteor trail with stellar trails produced by diurnal motion in a stationary camera §§; she applies the method to meteors photographed by Sykora at Tashkent in 1906–9.

8. *Telescopic Observations.*—The "effect of motion," or the influence of angular velocity upon apparent brightness, is of fundamental importance in the interpretation of telescopic observations of meteors; Öpik arranged certain experiments for the determination of this effect ‖‖; the simple formula $\Delta m = 2{\cdot}5 \log \frac{\omega + c}{c}$, where ω is the subjective angular velocity (the true angular velocity multiplied by the magnifying power) and c a constant, did not agree with the observations. Recently Öpik finds (unpublished) that c must be assumed variable: $\log c = 2{\cdot}72 - 0{\cdot}28m$, where m is the estimated subjective magnitude referred to naked-eye standards, thus $m = 6$ denotes limit of visibility; the formula represents excellently Öpik's experiments; apparently the "effect of motion" is not a function of ω alone, but depends upon the subjective magnitude also, in such a manner that faint objects show a much stronger effect than bright ones. The magnitudes in Boothroyd's telescopic observations ¶¶ should be re-reduced on this basis. Complications from the apparent illumination of the sky background are also present. Astapovič arranged experiments of his own and pointed out

* *Upsala Medd.*, No. 68, 1937.
† *Popular Astronomy*, **45**, 214, 1937.
‡ *H.A.*, **87**, No. 3, 1931. § *H.A.*, **82**, No. 8, 1937.
‖ *J.R.A.S. Canada*, **30**, 193, 1936, and **31**, 295, 1937.
¶ *Publ. Astr. Obs. Leningrad*, **7**, 66, 1936.
** *Proc. Nat. Acad.*, **19**, 34, 1933.
†† *J.R.A.S. Canada*, **29**, 210, 1935.
‡‡ *Proc. Nat. Acad.*, **19**, 1933; also *H.B.*, No. 894, 1934.
§§ *A.J. of Soviet Union*, **12**, 174, 1935.
‖‖ *H.C.*, No. 355, 1930. ¶¶ *H.C.*, No. 390, 1934.

the complication of the effect of motion *; in the same paper he gives a catalogue of 186 telescopic meteors, together with a comprehensive discussion of the material; he finds a very small variation of the number of telescopic meteors during the night, whereas Öpik did not find any variation.† On the contrary, Hoppe ‡, Lacchini § and Teichgräber ‖ find a definite increase in the frequency of telescopic meteors with the advancing hour of the night. The question seems to be definitely settled, in favour of a real increase of telescopic meteor frequency with decreasing zenith distance of the apex, by Knabe's 718 observations discussed by Williams ¶: the variation is, however, slow and requires a high value of the "apparent heliocentric velocity" from 3 to 3·5, according to Hoffmeister's theory.

9. *Heights.*—3540 meteor heights, mostly of sporadic meteors, obtained during the Arizona Expedition, are statistically studied by Öpik **, a number of correlations being derived. The strongest correlation connects the height with the distance of the apparent radiant from the apex, which doubtless is a velocity effect: meteors coming from the apex, *i.e.* the fastest ones, appear 23 km. higher than those coming from the antapex; on the basis of a provisional physical theory this leads to $a = 24{\cdot}5 \pm 1{\cdot}2$ km. for a mean heliocentric velocity 67 km./sec. as found directly by Öpik †† (or $c = 2{\cdot}2$ according to Hoffmeister), whereas a parabolic mean heliocentric velocity of 42 km./sec. ($c = 1{\cdot}4$) leads to $a = 11{\cdot}5$ km.; here a denotes the difference in level for which the atmospheric density changes in the ratio 10 : 1. On the other hand, the correlation of luminosity and height gives an increase of the height of appearance by $0{\cdot}30 \pm 0{\cdot}30$ km., and a decrease of the height of disappearance by $3{\cdot}64 \pm 0{\cdot}19$ km. per magnitude of increasing luminosity; the latter figure leads to an independent value of $a = 24{\cdot}8 \pm 1{\cdot}7$ km., in excellent agreement with the above hypothesis of hyperbolic mean velocity ($c = 2{\cdot}2$), and in definite contradiction to the assumption of a parabolic or smaller mean velocity. The theoretical basis of the above deductions is purely differential, and yields identical results for all hitherto published physical theories of meteor phenomena (Lindemann and Dobson, Sparrow, Öpik and others). Thus, we find in the statistics of meteor heights an independent argument in favour of the hyperbolic mean velocity of the sporadic meteors. Further, a "night effect" is found indicating a decrease of the average height by $0{\cdot}30 \pm 0{\cdot}09$ km. per hour, possibly interpreted as nocturnal cooling. A seasonal variation in height, more or less corresponding to the annual temperature curve of the upper atmosphere, is indicated; the amplitude is $3{\cdot}7 \pm 0{\cdot}7$ km. For meteors of constant velocity and luminosity the cosmic spread in height is found equal to $\pm$ 8 km. (p.e.); variation in chemical composition, shape and luminous efficiency are probably chiefly responsible for the cosmic spread. The comparatively large heights found for the major showers (Leonids, Perseids, Orionids) are possibly explained by their chemical composition (stone, according

* *A.J. of Soviet Union*, **12**, 60, 1935.
‡ *A.N.*, **251**, 125, 1934.
‖ *A.N.*, **262**, 485, 1937.
** *H.A.*, **105**, 549, 1937.
† *Tartu Obs. Publ.*, **27**, No. 2, 1930.
§ *Publ. R. Oss. Astr. Trieste*, **2**, 157, 1934.
¶ *Proc. Am. Phil. Soc.*, **81**, 505, 1939.
†† *H.C.*, No. 391, 1934.

to Millman), perhaps also by their shape, as postulated by Öpik from cosmogonical reasons.*

All the statistical averages of the heights in Öpik's paper are harmonic mean values, which correspond to the character of the observational error, which is symmetrical in parallax, not in height. Only harmonic mean heights are free from a peculiar systematic error; the harmonic mean observed height is equal to the harmonic mean true height, whereas the arithmetic mean observed height exceeds systematically the true arithmetic mean by an amount which is proportional to the square of the accidental error of observation; the error in different actual cases amounts to from 3 to 11 per cent. of the height, and thus is by no means negligible. Harmonic mean heights have been calculated earlier by Öpik in the case of telescopic meteors †, whereas formerly Hoffmeister did draw attention to the systematic error mentioned above.‡ The importance of the harmonic mean height has been recognized also by Maltzev §, and by Astapovič and Fedynsky.‖

An important source of systematic error in meteor heights is pointed out by Astapovič ¶: the distance, hence also the intrinsic brightness of different points of the meteor trajectory, is not the same for the two observers; therefore, the limit of visibility takes place also at different points, and the points of appearance and disappearance are not the same; these points are systematically displaced along the trajectory in such a manner as to reduce the distance from the given observer. However, in the case of the small base of the Arizona observations the above error must be comparatively small.

10. *Frequency of Magnitudes.*—Watson studies the luminosity function of the Giacobinid meteors, and concludes that the distribution of masses is different from that of the Perseids and the Leonids.** In another paper he derives the distribution of meteoric masses in interstellar space ††, basing his results upon the velocity observations of Boothroyd and Öpik. Williams finds between third and seventh magnitudes an increment ratio $N(m+1)/N(m) = 2{\cdot}29 \pm 0{\cdot}16$ ‡‡, whereas Millman finds a larger ratio of 3·5 for photographic meteors (*cf.* above); these two figures agree with different former results, indicating that the increase in meteor numbers becomes slower with the fainter magnitudes. On the other hand, Kusmin finds that an average increment ratio near 2·5, possibly valid up to the smallest particles producing interstellar absorption, is in good agreement with the observed absolute coefficient of absorption of light in space, as well as with the observed number of visible hyperbolic meteors.§§ This important result makes us hope that the gap between observable meteors (m brighter than 10), and the dust particles ($m \sim 25$) which are chiefly responsible for interstellar absorption, is not as insuperable as it may seem at the first glance.

11. *Physical Theories, Cosmogony, Meteor Craters.*—Öpik develops a semi-empirical theory of the radiation of meteors which is considered as being

* *Tartu Obs. Publ.*, **28**, No. 6, 1936.
‡ *Met. Zs.*, **44**, 464, 1927.
‖ *C.R. Acad. U.R.S.S.*, May 1935.
** *H.B.*, No. 895, 1934.
‡‡ *A.J.*, No. 1110, 1939.
† *Tartu Obs. Publ.*, **27**, No. 2, 1930.
§ *Tashkent Obs. Bull.*, **3**, 57, 1934.
¶ *A.J. of Soviet Union*, **12**, 252, 1935.
†† *H.A.*, **105**, 623, 1937.
§§ *Tartu Obs. Publ.*, **30**, No. 1, 1938.

chiefly produced by atomic collisions * ; possible complications from the variable degree of ionization of the moving atom are mentioned in section 3 of this report. Further, Öpik published a "Basis of the Physical Theory of Meteor Phenomena" †, which considers in much detail the different phases of the physical processes occurring during the flight of a meteor in the atmosphere ; fissure and spraying of the liquid, influence of rotation, conditions of the formation of an air cap, the heat transfer within the meteor nucleus and other phenomena are investigated ; the paper is considered preparatory to a detailed numerical theory of meteor phenomena. Hoppe also published a dissertation on the physical phenomena produced by the flight of meteors in the terrestrial atmosphere.‡ Fisher studies theoretically the phenomena produced by the flight of large meteors ("fireballs").§ There are many points of agreement between these theories and some older theories.

Corlin studies theoretically the building of larger bodies out of small particles in interstellar space,‖ with special consideration of electrical processes. Öpik considers the destructive action of meteoric impact ¶ and applies it to the theory of formation of meteor craters ; also he studies the effect of collisions of meteors in space, and finds that solar stone meteors lose as a consequence of the grinding by hyperbolic meteors a layer of 0·1 cm. in 3000 million years, whereas iron meteors lose ten times less ; in this way the peculiar absence or rarity of faint members among the Leonids and the Perseids (which are stones, *cf.* above) may be explained by their destruction through grinding, the calculated age being in agreement with the short time-scale ; an average velocity of rotation of the order of 30 m./sec. for naked-eye meteors may represent another consequence of the mutual collisions, a circumstance important for the physical theory of meteor phenomena.

The stability of nearly parabolic members (meteors or comets) of the solar system is considered by Öpik from the standpoint of stellar perturbations ** ; it is estimated that, although the possible limits of the solar system may reach as far as 10^6 astronomical units, objects observable from the Earth are not likely to come from distances exceeding 10^4 astronomical units. The persistence of extra-solar double meteor systems is studied theoretically from the same standpoint by Hoffleit †† ; her statistical analysis of meteor counts indicates a slight, though uncertain, excess in the frequency of naked-eye meteors, separated in time by 10 seconds or less, as compared with an accidental distribution ; the excess, however, is in agreement with theoretical expectations based upon an observed frequency of 16 per cent. of double telescopic meteors. Moisseiev published very extensive theoretical treatises

* *Acta Univ. Tartu A.*, **26**, No. 2, 1933 ; *H.R.*, 100.
† *Tartu Obs. Publ.*, **29**, No. 5, 1937.
‡ *A.N.*, **262**, 169, 1937.
§ *H.C.*, No. 385, 1934.
‖ *Zs. f. Ap.*, **15**, 239, 1938, and **18**, 1, 1939.
¶ *Tartu Obs. Publ.*, **28**, No. 6, 1936.
** *Proc. Am. Acad. of Arts and Sci.*, **67**, 169, 1932.
†† *H.C.*, No. 420, 1937.

on the origin of comets, meteors and cosmic dust.* Paneth determines ages of meteorites from their helium content and finds figures which are all below 3000 million years †; Öpik finds in Paneth's results an additional argument in favour of the short time-scale for our universe. ‡

The connection between meteors and different phenomena of the ionosphere has been studied by many authors. Teichgraeber finds from his own observations § that the intensity of the luminescence of the nocturnal sky consists of two components: the diffuse light of the sky which does not vary during the night; and the luminous bands which increase in intensity toward sunrise; the latter are possibly connected with meteoric dust. Astapovič publishes and discusses important data relating to the great meteorite fall in Central Siberia in 1908 ‖; he tries to estimate the velocity and the real path, as far as is possible from the scanty material; the radiant he finds somewhere near $\alpha = 20^\circ$, $\delta = -12^\circ$; the total energy of the collision he estimates at $10^{20} - 10^{21}$ ergs.

The list of suspected or certain meteorite craters increases steadily; reviews of the subject are given by Spencer ¶ and by Watson.** For the earliest known object of this class, the group of the Kaalijärv craters in Estonia, excavations by Reinvald †† yielded at least thirty fragments of meteoric nickel iron which were analysed by Spencer ‡‡; the meteoric origin of these craters stands now without doubt.

12. *Textbooks.*—An excellent guide in modern meteor research is C. Hoffmeister's book, *Die Meteore*, Leipzig, 1937. The intention of this book is to give a complete view of the recent accomplishments of meteor science; it is strongly coloured by Hoffmeister's personal views, at the same time rendering justice to the work of others.

E. ÖPIK

Tartu, Estonia:
January 1940.

* *Publ. Astroph. Inst. Moscow*, **5**, No. 1, 1930, and No. 2, 1933.
† *Nature*, **125**, 490, 1930, *et al.*
‡ *Popular Astronomy*, **41**, No. 2, 1933.
§ *A.N.*, **267**, 337, 1938.
‖ *A.J. of Soviet Union*, **10**, 1933; also *Quart. J.R.M.S.*, **60**, 493, 1933.
¶ *Smithsonian Report for 1933*, p. 307; *Proc. Geol. Assoc.*, **45**, 407, 1934.
** *Popular Astronomy*, **44**, No. 1, 1936.
†† *The Sky*, **2**, No. 6, 6, 1938.
‡‡ *Mineralogical Magazine*, **25**, 75, 1938.

COMETS

Six new comets and six expected periodic comets were detected in 1939. Comet Kozik-Peltier (1939 *a*) was discovered by Peltier on January 20 when its magnitude was 8. It was described as diffuse, with central condensation or nucleus, and the tail was about 1° long. Observations of the comet were made by a number of members of the British Astronomical Association, including Dr. R. Waterfield, Messrs. G. F. Kellaway and F. Sargent, and some of their results were utilised in the computation of an orbit. M. Przybylski has undertaken the computation of a definitive orbit of this comet.

Comet Väisälä (1939 *b*) was at first believed to be a minor planet and was named 1939 CB, but on March 17 a telegram from Turku announced that it was a comet with a period of about 10 years. Miss L. Oterma has undertaken the computation of a definitive orbit of this comet.

Comet Jurlof-Achmarof-Hassel was discovered by Hassel at Oslo on April 16, but later it was announced that several others had made independent discoveries of the object. As not more than three names are given in the description of a comet it was decided to use the above title, or more briefly, 1939 *d*. A number of B.A.A. members kept the object under observation, and sketches of its appearance were made by Messrs. S. W. Elliott and W. T. Gayfer. Captain E. W. Barlow made an independent discovery of the comet, and Dr. R. L. Waterfield at Headley took a number of photographs from April 19 to 25. It is remarkable that while the photograph on April 21 showed a tail extending over 9°, the photograph on the next night showed that the tail had practically disappeared, and a number of others confirmed this fact from visual observations. The comet had passed perihelion 12 days previously, for which reason the disappearance of the tail was not due to the Sun but to some internal cataclysm. Dr. M. Bielicki is computing a definitive orbit of this comet.

Comet 1925 II was identified with the object discovered by J. W. Jackson on June 12.

Kaminsky's comet was discovered on July 24, but very few observations were subsequently made and an orbit was not computed.

Comet Rigollet (1939 *h*) was discovered on July 29 by Rigollet, its magnitude being 8. It was described as diffuse, with central condensation or nucleus. Cunningham suggested that it might be identical with Comet 1788 II, and a comparison of the elements of the two comets supports this view.

Comet Friend (1939 *n*) was discovered on November 4 by Friend at Harvard. Drs. Steavenson and Fry observed this comet on the nights of November 8 and 9, and they described it as diffuse, with some central condensation but no tail ; the magnitude was between 8 and 9.

Comet Pons-Winnecke (1939 *c*) was rediscovered by Jeffers at Lick on March 17, its magnitude being 17. Major A. E. Levin and Mr. J. G. Porter had computed the perturbations of the planets on this comet by

Elements of the Orbits of

Comet	T (U.T.)	ω	Ω	i
		° ′ ″	° ′ ″	° ′ ″
1939 *a* Kozik-Peltier	1939 Feb. 6·77064	169 2 3·9	288 43 25·6	63 31 56·7
1939 *b* Väisälä	1939 Apr. 26·08618	44 20 22·1	135 33 50·5	11 16 22·0
1939 *c* Pons-Winnecke	1939 June 22·7542	169 21 24·5	96 48 21·2	20 8 24·4
1939 *d* Jurlof-Achmarof-Hassel	1939 Apr. 10·10952	89 10 29·5	311 30 49·6	138 13 16·0
1939 *e* Kopff	1939 Mar. 12·7818	19 48 19·4	264 9 12·4	8 42 57·6
Brooks (2)	1939 Sept. 15·6943	195 39 51·4	177 42 41·3	5 32 44·6
1939 *h* Rigollet	1939 Aug. 9·46490	29 17 53·4	355 7 17·6	64 11 58·7
1939 *k* Tuttle	1939 Nov. 10·78	206 57 40·0	269 50 35·2	54 39 15·1
1933 III Giacobini-Zinner	1940 Feb. 17·3887	171 49 52·5	196 12 51·9	30 45 16·0
1939 *m* = 1932 IX Faye	1940 Apr. 23·5	200 17 24·0	206 23 16·8	10 34 19·2
1939 *n* Friend	1939 Nov. 6·149	128 31 0	198 11 0	92 7 0

Wherever possible the most recent orbit derived from the longest time-interval has been 4, Cunningham; 5, Davidson; 6, Harris; 7, Henderson; 8, Hoffmann; 9, Levin; 17, Przybylski; 18, Smiley; 19, Sumner; 20, Väisälä; 21, Vergnano.

Cowell's method, and the elements of the orbit and an ephemeris appeared in the *B.A.A. Handbook* for 1939. The comet was very close to its predicted position, and perihelion was only $0^d{\cdot}75$ earlier than the assumed date. It came within 10 million miles from the Earth on July 3.

Comet Kopff (1939 *e*) was rediscovered by van Biesbroeck on April 22 close to the position predicted by Messrs. W. P. Henderson and P. J. Harris (see *B.A.A. Handbook* for 1939). Perihelion passage took place on March 12·7818, about $0^d{\cdot}37$ later than the assumed date.

Comet Brooks (2) was rediscovered on June 17 by Jeffers and Miss Adams at Lick. Its magnitude was 17, and it was described as diffuse, without condensation or nucleus. The perturbations of Jupiter and Saturn on this comet had been computed by Mr. F. R. Cripps, and the elements of the orbit and the ephemeris were given in the *B.A.A. Handbook* for 1939. It was close to the predicted place, and perihelion passage was $0^d{\cdot}4$ later than that assumed in the computation of the ephemeris.

Comet Tuttle (1939 *k*) was rediscovered on August 12 by Jeffers and Moore at Lick. Its magnitude was given as 18, and it was described as diffuse, with central condensation. The late Dr. A. C. D. Crommelin gave the elements of the orbit and an ephemeris for this comet in the *B.A.A. Handbook* for 1939, perturbations of Jupiter and Saturn having been applied,

Comets observed during 1939

Comet	q	Period (years)	Equinox	Computers	Reference
1939 *a*	0·71635	8170	1939·0	4, 10, 11, 17, 19	*U.A.I. Circ.*, 746
1939 *b*	1·76245	10·57833	1950·0	14, 20	*U.A.I. Circ.*, 767
1939 *c*	1·10169	6·09040	1950·0	9, 16	*B.A.A. Handbook*
1939 *d*	0·52853	329	1939·0	1, 5, 13, 18	*U.A.I. Circ.*, 769
1939 *e*	1·81826	6·55592	1950·0	6, 7	*B.A.A. Handbook*
(Brooks)	1·87215	6·94877	1950·0	2	*B.A.A. Handbook*
1939 *h*	0·748459	150	1939·0	8, 12, 13	*U.A.I. Circ.*, 795
1939 *k*	1·02225	13·60598	1950·0	3	*B.A.A. Handbook*
1939 *l*	0·99547	6·5877	1950·0	2	*B.A.A. Handbook*
1939 *m*	3·80291	7·41606	1950·0	6, 7	*B.A.A. Handbook*
1939 *n*	0·93770	...	1939·0	12, 21 and Berkeley computers	*U.A.I. Circ.*, 799

taken. The various computers are indicated by: 1, Buchan; 2, Cripps: 3, Crommelin; 10, Kahrstedt; 11, Kellaway; 12, Maxwell; 13, Möller; 14, Oterma; 15, Pollock; 16, Porter;

and the comet was easily found from the ephemeris. Perihelion passage was about $0^d{\cdot}7$ later than the assumed date.

Comet Giacobini-Zinner (1933 III) was rediscovered by van Biesbroeck on October 15 very close to its predicted place. Mr. F. R. Cripps applied the perturbations of Jupiter and Saturn to the 1933 elements, and perihelion passage took place $0^d{\cdot}25$ later than that assumed (see *B.A.A. Handbook* for 1939).

Comet Faye (1939 *m*) = 1932 IX was rediscovered by Jeffers at Lick on November 3. It was described as diffuse, with central condensation. Messrs. W. P. Henderson and P. J. Harris applied the perturbations of Jupiter and Saturn to the 1933 elements and published the results in the *B.A.A. Handbook* for 1939. The comet was easily found from the ephemeris, and perihelion passage will be on April 23·5, which is half a day later than that assumed in the computation of the ephemeris.

The elements of the orbits of comets observed in 1939 are given in the accompanying table. In some cases a number of orbits were computed and the computers are indicated by reference numbers. Wherever possible the most recent orbit derived from the longest time-intervals has been given.

M. DAVIDSON

SOLAR ACTIVITY

Sunspots.—After an exceptionally high maximum in 1937–38, sunspot activity is now definitely declining. The year 1939 was, however, a period of considerable activity especially from April to September. The following table shows the relative activity for the years 1936–39 :—

Year	1936	1937	1938	1939
Sunspot Number : (Zürich)	80	114	110	89*
Large sunspots : ⩾ 1000 units †	7	16	14	10
Magnetic storms ‡	9(0)	26(3)	28(5)	21(7)

* Provisional value.

† Maximum area, corrected for foreshortening and expressed in millionths of the Sun's hemisphere.

‡ As recorded at Abinger ; "great" storms are indicated in brackets.

The time (U.T.) of central meridian passage, together with the latitude, of each of the ten groups of spots ⩾ 1000 millionths in area are as follows :—

(1)	Apr. 16·1	12° N.	(6)	Aug. 21·9	13° N.
(2)	Apr. 26·1	27° N.	(7)	Sept. 1·0	15° S.
(3)	Apr. 26·6	16° S.	(8)	Sept. 10·5	14° S.
(4)	July 8·2	6° N.	(9)	Sept. 28·0	13° S.
(5)	July 9·3	4° S.	(10)	Oct. 26·0	8° S.

Two of the above groups, Nos. 7 and 8, exceeded 2000 millionths in area, the larger group, No. 7, reaching 2800 millionths. Groups 2 and 7 were of very rapid growth. Group 1 was active spectroscopically, twenty-two associated bright eruptions being collectively recorded in the Zürich *Bulletin*. The central meridian passage of this group was associated with a "great" magnetic storm. Groups 2 and 3, nearly on the same meridian but on opposite sides of the Sun's equator, were also active. Two magnetic storms, one of them "great," were associated with these spots. Groups 7 and 8 were both associated with intense chromospheric eruptions (*Observatory*, January 1940, p. 8), but no unusual magnetic disturbance occurred near the time of their respective central meridian passage.

H. W. NEWTON

Prominences.—The year 1939 has witnessed a further fall in prominence activity, very pronounced in the case of the profile areas, which showed an increase in 1938.

The mean daily areas and numbers of calcium prominences as derived from Kodaikanal photographs are as follows :—

	Areas		
	North	South	Total
1939 January to June	2·31	2·33	4·64 sq. mins.
July to December	2·76	2·66	5·42 ,,

Numbers

	North	South	Total
1939 January to June	6·35	6·20	12·55
July to December	7·62	7·04	14·66

There has been a decrease of 39 per cent. in prominence areas and a decrease of 9 per cent. in prominence numbers from the values of the previous year. The activity in the two hemispheres north and south is nearly equal in respect of both areas and numbers. The distribution of areas in latitude showed the maximum activity confined to near latitude 30° in both the hemispheres. In the first half-year there was a peak of activity in the southern hemisphere near latitude 20°, which was obliterated by a greater increase of activity near 30° during the second half-year. The distribution of numbers is nearly uniform from the equator to latitude 50°.

There were 59 metallic prominences observed during 1939, as against 48 in the previous year. Of these, 22 were in the northern hemisphere and 37 in the southern, and all of them were observed from the equator to latitude 33°. Displacements of the hydrogen line in the chromosphere and prominences observed with the spectroscope numbered 451 as against 323 in 1938. Of these 238 were towards the red, 195 towards the violet and 18 both ways simultaneously. The largest displacement noticed was 9 A. to violet.

Bright reversals of the *Hα* line on the Sun's disc observed with the spectroscope in the neighbourhood of sunspots numbered 963 as against 872 in the previous year. The displacements observed in the neighbourhood of sunspots numbered 64, while in 1938 they came to 65. Of these 34 were towards the red, 13 towards the violet and 17 both ways simultaneously. D_3 was observed as a dark line on 720 occasions as compared with 789 during the previous year.

The displacements observed in prominences with the spectrohelioscope numbered 282 as against 187 in the previous year. Of these 140 were in the northern hemisphere and 142 in the southern, and 136 were on the east limb and 146 on the west limb. Displacements to the red numbered 154 and those to the violet 127; there was also one displacement which was seen both to red and violet simultaneously. The largest displacement in prominences observed in 1939 was 4·8 A. to red.

Eruptive prominences on the limb were photographed on February 6, May 2 and 31, September 1 and December 16. The prominences of February 6 on the N.E. limb rose to a height of more than 10′. The prominence of September 1 on the S.E. limb showed the largest displacements of 9 A. to violet at top and 6 A. to red at base. It was connected with an active spot (Kodaikanal No. 7157). A prominence of very large extent was photographed on December 1. Its base extended from 36° N. to 38° S. on the west limb. Its height was only 80″, but the area it covered was nearly 10 square minutes. Other important phenomena noted during the period are the breaking up of *Hα* dark markings. Instances of breaking up of markings were observed on August 26 and September 2 and 12. The last

of these was remarkable inasmuch as a big marking which was observed for a number of days completely disappeared with great suddenness, leaving a bright marking in its place.

The mean daily areas of prominences projected on the disc as hydrogen absorption markings were 9735 millionths of the Sun's visible hemisphere, as against 10161 in 1938. This means a 4 per cent. decrease from the previous year. Their distribution in latitude is nearly similar to that of prominences at the limb, with the peaks very much pronounced. But in the second half of the year the peak near 20°, unlike the prominences, has not subsided but has moved towards the equator by 5°.

A. L. NARAYAN

DOUBLE STARS

New Pairs.—Burns (*P.A.S.P.*, **51**, 50) reports a distant physical companion to τ Cygni (ADS 14787), van de Kamp (*A.J.*, **48**, 80) to ADS 9352, van Maanen (*I.A.U. Circ.* 774) to the proper motion star Lalande 21258. Luyten (*H.O.B.* 910) gives a double star with large proper motion, Bemporad (*Contr. Astrofis. Catania*, 42) reports the discovery of a quintuple star on astrographic plates and Oriano (*L'Astronomie*, **53**, 355) writes on an invisible companion to Mizar B.

Measures.—Baize (*J.d.O.*, **22**, 11 and 169) has published further measures with the Paris 12-inch refractor, Lacchini (*Mem. Soc. Ast. Ital.*, xi, 3) with a 10-inch, Woolley (*M.N.*, **99**, 742) with the Cambridge 12- and 8-inch refractors; *Ricerche Astronomiche Spec. Vatic.*, i, 1, contains measures made with the 16-inch refractor by Tibor, Stein and others, while Schembor gives another series of measures with the 8-inch in *A.N.*, **268**, 257. Photographic measurements are given by Stearns (*A.J.*, **48**, 11).

Muller has published a list of provisional distances for 15 standard pairs (*L'Astronomie*, **53**, 323; *J.d.O.*, **22**, 181).

Orbits:—

ADS	Computer	*P*	*a*	*e*	Reference
			"		
2799	McLeod	56·5	0·41	0·72	*A.J.*, **47**, 199
5423	Rakowiecki	50·11	7·77	0·568	*Wiadom. Matemat.*, 47
6993	Adams	15·04	0·21	0·61	*P.A.S.P.*, **51**, 116
8148	Bezold	184·52	1·8707	0·6388	*A.N.*, **267**, 221
8695	Schmeidler	674·23	1·897	0·49569	*A.N.*, **268**, 151
9182	Bezold	341·35	1·612	0·1445	*A.N.*, **267**, 221
9494	Gennaro	279·99	4·304	0·2469	*Padova Publ.*, 57
9578	Aller	199	1·26	0·68	*A.N.*, **268**, 23
9716	Stephens	56·05	0·8754	0·5912	*P.A.A.S.*, **9**, 170
9744	McLeod	11·7	0·23	0·55	*A.J.*, **47**, 155
10345	Bezold	1544·0	6·917	0·673	*A.N.*, **267**, 221
11871	Rechtenstamm	61·203	1·24	0·2489	*A.N.*, **268**, 229
14761	Olsen	43·77	0·241	0·505	*P.A.S.P.*, **51**, 171
BD +45° 2505	Zimmermann	11·25	0·71	0·59	*A.N.*, **268**, 157

Alden, from measures on parallax plates, discusses the orbits of α Tucani, and ν Octantis (*A.J.*, **47**, 185 and **48**, 81). Danjon (*Bull. Ast.*, **11**, 191),

Rakowiecki (*Wiadom. Matemat.*, 42 and *Prac. Matem.-Fizyc.*, 46), Rabe (*A.N.*, **268**, 1) and McLeod (*A.J.*, **48**, 119) deal with orbit methods; Baize (*Bull. Ast.*, **11**, 231) gives a list of errata to his catalogue of orbits.

Miscellaneous.—Gondolatsch (*A.N.*, **268**, 133) determines the position, proper motion and mass ratio for α Centauri, van de Kamp the parallax and mass ratio for 85 Pegasi, β 648, ζ Herculis, β Delphini (*A.J.*, **47**, 149, 152, 168, 189), 70 Ophiuchi and 9 Argus (*A.J.*, **48**, 17, 92).

Bhaskaran (*A.J.*, **47**, 172) has a note on ADS 366, Baize (*J.d.O.*, **21**, 185) on the optical pair ADS 3864; he also writes on *Mira* as a double star (*L'Astronomie*, **53**, 360), optical double stars (*L'Astronomie*, **52**, 517 and 556) and what we know about double stars (*L'Astronomie*, **53**, 241).

Woolley has a note on eccentric long period binaries (*Observatory*, **61**, 323). Kuiper discusses the empirical mass-luminosity relation (*Ap. J.*, **88**, 472). Hopmann has made statistical investigations of visual double stars (*A.N.*, **269**, 81) and Luyten publishes a discussion of double stars with common proper motion (*Publ. Minnesota*, ii, 9).

W. H. VAN DEN BOS

Errata

M.N., **99**, No. 4, Council Note on *Stellar Motions*:

P. 374, last footnote, *for* complications *read* compilations.

P. 375, line 24, *for* $\phi = \tau/R_0$ *read* $\sin \phi = \tau/2R_0$.

LIST OF PUBLIC INSTITUTIONS AND OF PERSONS WHO HAVE CONTRIBUTED TO THE LIBRARY, ETC., DURING THE YEAR 1939

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Bohemia:	Observatory of the Czech University, Prague-Smichov State Observatory of the Czech Republic, Prague-Klementinum

Bohemia:	Geophysical Institute of the German University, Prague
	State Observatory (Konkoly), Presov
	Masaryk University, Brno
Brazil:	Rio de Janeiro Observatory
Canada:	Royal Astronomical Society of Canada
	Royal Canadian Institute, Toronto
	Dominion Observatory, Ottawa
	Dominion Astrophysical Observatory, Victoria, B.C.
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China:	Hong Kong Observatory
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East Indies:	Bosscha-Sterrewacht, Lembang, Java
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Esthonia:	Tartu Observatory
Finland:	Society of Sciences, Helsinki
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	Société Astronomique de France
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France:
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Bureau des Longitudes
École Polytechnique, Paris
Institut d'Optique
Rédacteurs, *Journal des Observateurs*

Germany:
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Bayerische Akademie der Wissenschaften, München
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Phys. Tech. Reichsanstalt, Berlin-Charlottenburg
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Greece:	Athens Observatory
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Italy:	R. Accademia d'Italia
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Yugoslavia:	Académie Royale Serbe, Belgrade

The following Periodicals were purchased:—

Publications of the American Astronomical Society
Discovery
Empire Survey Review
Journal of the Optical Society of America
Journal of Scientific Instruments
The Monthly Evening Sky Map
The Philosophical Magazine
Review of Scientific Instruments
The Scientific American
The Telescope
Zeitschrift für Astrophysik

ADDRESS

Delivered by the President, Professor H. C. Plummer, on the Award of the Gold Medal to Dr. E. P. Hubble

The award of the Gold Medal is a practice which we have observed annually almost without intermission for more than a century. Year by year it has given us the privilege of paying tribute to some individual work which we agree in thinking of outstanding importance to astronomy. More than that, it has been frequently associated in recent years with the opportunity of hearing an account of this work from the lips of the Medallist himself. Unhappily in the present year there is no prospect of Dr. Hubble making the journey from California. But though we are debarred from welcoming him in person, we are not debarred from adding his name to the list of those whom our Society has delighted to honour in the past.

In paying recognition to an individual achievement, it is natural that we should recall the earlier progress which has been made in the same direction and some of the steps which have made ultimate success possible. At an earlier stage in the development of science such a review might have involved a suspicion of disparagement. The organic structure of science is now better understood and there is no danger. There is no need to ignore the gradual process by which a knowledge of the nebulæ has been gained, or the successive steps in the evolution of the reflecting telescope, in order to see a particular and later stage as though it were isolated from all that had gone before. A growing knowledge of the nebulæ and the development of the reflector are not of course synonymous, but they have always been associated in a remarkable degree. The first has depended largely on the second, and the second in turn has gained its greatest triumphs in the field of the nebulæ. It has been a trial of strength.

The first optical instrument was presumably a plane mirror. It was of burnished copper, and specimens are to be seen in our museums. It was an article of the toilet. But the first instruments to be applied in astronomy were the refracting telescopes employed in the first decade of the seventeenth century by Galileo and in England by Thomas Harriot, the friend of Raleigh. Sixty years later the reflecting telescope was invented independently and almost simultaneously by three men in three different forms. These were the form devised by James Gregory and published by him in his *Optica Promota*, that made by Newton and presented to the Royal Society and that invented by Cassegrain. But in spite of the notorious chromatic defects of refracting telescopes, reflectors found no important application for a whole century. The chief artist in this line was James Short (1710–68), a pupil of Colin Maclaurin at Edinburgh. He is credited with being the first to give the speculum a parabolic figure. His instruments were mostly Gregorians, but in one at least he adopted the design of

Cassegrain. Thus some practical progress had been made even before the days of W. Herschel (1738–1822), who began work with a small Newtonian reflector in 1775. His large speculum of $49\frac{1}{2}$ inches aperture and weighing nearly a ton was finished in 1789, and his catalogue of 2500 nebular objects is virtually the foundation of the subject. This classic work must now be dismissed with two remarks. It is the outcome of a passion to explore the depths of space to the utmost attainable limit, and our Medallist has shown that he has inherited that passion. The other point to be observed is the early recognition of the limitation imposed by our climate on work of this kind ; Herschel has recorded that a power of 1000 could only be used with advantage for 100 hours in the average year.

Sir John Herschel (1792–1871) extended the survey to the Southern hemisphere and brought the number of objects catalogued to over 5000. He was also the first to make a detailed study of the Magellanic Clouds. But of all his varied and distinguished scientific work, that which contained the germ of the most important future progress may have been his researches in photography (this is the centenary of his Royal Society paper in which he mentions hyposulphite of soda as a fixing agent), which began just over a century ago. The next development of the reflector came from W. Lassell (1799–1880), who with some help from James Nasmyth (of steam-hammer fame) ground first a 2-foot and then a 4-foot speculum. It was with the smaller of these that he discovered the satellite of Neptune, two satellites of Uranus and, independently of Bond, Hyperion, the eighth satellite of Saturn. He also added 600 to the list of nebulæ. His telescopes were equatorially mounted, and were thus given the same advantages as refractors. In the end (1861) he removed his observatory to the more favourable climate of Malta.

But little progress was made in recognizing the characteristic nebular forms by visual means until the great 6 ft. speculum was made and installed (1843) by the third Earl of Rosse (1800–67). Then for the first time examples of the spiral form were seen in proper shape, the Orion nebula was carefully drawn and several nebulæ were resolved into stars. Indeed imagination outstripped the positively observed facts, and all nebulæ without distinction were held to be stellar aggregates. In 1850 Humboldt introduced the term "Weltinseln," which has doubtless suggested the more modern term "Island Universes."

This stage marks the high-water mark in the progress of nebular research by purely visual methods.

Before the descriptive study of nebulæ was resumed thirty years later, three important things had happened. Liebig's discovery of a method for depositing metal on glass was applied by Steinheil (1856) and by Foucault (1857) to astronomical mirrors. From that point the use of speculum metal was entirely superseded. Foucault also devised the well-known tests which helped greatly in attaining the desired figure. In the second place, photography began to make its way slowly into astronomical practice. Early stages were marked by Bond's lunar photographs in the 1851 Exhibition, and De la Rue's photographs of the Moon and of the solar eclipse in 1860.

But little was to be expected before the dry plate came into general use (1880).

The third event was the application of spectrum analysis, and among the earliest results of Huggins (1824–1910) was the correction of a view which had been accepted too hastily. The nebulæ did not form a single class of objects. This was clear as early as 1864. While one class presented a stellar and indeed, as was later shown, a predominantly solar type of spectrum, the other presented a quite characteristic type of its own. The latter, whether planetary or diffuse in appearance, tended towards the galactic plane and defied attempts to resolve them into stars. In contrast the former avoided the galactic plane and might represent far-distant island systems, but much work was required before their status could be established.

When Common (1841–1903) acquired first an 18-inch and later a 3-foot silver-on-glass mirror, both by Calver, the broader distinctions between nebular objects may have been known, but very little about their forms. His early photograph of the Orion nebula was therefore an original contribution and received due recognition in 1884. Subsequently he made a 5-foot mirror with his own hands, and this found its way to Harvard. But it is the 3-foot Calver reflector, which was sold to Edward Crossley and by him presented to the Lick Observatory, which has the more important history.

Isaac Roberts (1829–1904), employing a 20-inch Grubb reflector, extended photography to a far greater variety of interesting objects. His photograph of the Andromeda nebula in 1888 was the first to reveal its spiral character. This object, of which the Cassegrain image in the 100-inch reflector is about 6 feet long, is now so familiar that it seems hard to realize that its nature remained so long concealed.

This account of the more important steps in the development of the reflecting telescope and in the investigation of the nebulæ justifies a little pride in the work which has been accomplished in this country—the catalogues of Dreyer, published by the R.A.S., also deserve mention—chiefly by British amateur astronomers. But this satisfaction must now be tempered by the reflection that the progress made has now culminated in the production of instruments of such a size that they can no longer be profitably used in this climate.

The Crossley reflector at the Lick Observatory was not an immediate success in its new home. It was a novel type of instrument, the figure of the mirror was not equal to the standard of the present day, and its mounting was extremely inconvenient. When, therefore, Keeler returned to the observatory as Director, the staff was greatly relieved when he reserved the reflector for his own use. A few improvements in the design were then introduced with great deliberation. Only after these changes was a programme of exposures begun. It was cut short unhappily by Keeler's untimely death. But within a few months he had made the notable discovery that the spiral was in the statistical sense the predominant type of nebula, and that this type was extremely numerous. As, to quote later evidence, exposures with the 100-inch approach the practical limit, the number of

nebulæ in a field near the galactic pole begins to surpass the number of the stars and, according to Dr. Hubble's figures, 80 per cent. of them are spirals. Surveys have been carried out to different limits of magnitude, and the facts have only become clearer and more precise since the days of Keeler.

The Crossley reflector has been completely reconstructed since that time and its record of work has been remarkable. But in size it has been far outstripped. The first steps taken to improve the quality and performance of mirrors were made by G. W. Ritchey, who not only constructed new instruments but used them very effectively as well. The 60-inch telescope at Mount Wilson was made and erected by him in August 1908. At that date the 100-inch disc was lying unworked in the hope that a better would be delivered. When that hope faded the instrument was completed, and the early fears seem to have been completely falsified. Other well-known instruments of intermediate size have been erected elsewhere, but the 60-inch and the 100-inch are at present, pending the completion of the 200-inch, the most powerful combination in one observatory. Dr. Hubble showed his appreciation of the possibilities they presented when he attached himself to the Mount Wilson Observatory in the year 1919.

By that date four classes of object were known as permanent features of the sky. First, there are the stars extending continuously from our nearest neighbours to the undefined limits of the galactic system. Secondly, owing to the tendency of these stars to cluster, there are stellar aggregates which may present a nebular appearance but are more or less easily resolved. Such are the Præsepe cluster resolved by Galileo and the ω Centauri cluster noted by Halley. Thirdly, there are the gas nebulæ showing an emission spectrum and unresolved into stars. They are congregated towards the galactic plane and are not attributed to the space beyond the galactic limits, except in so far as they appear as parts of the extra-galactic nebulæ. Finally, there are the nebulæ predominantly spiral in form and now known as extra-galactic. Already in 1919 Dr. H. D. Curtis had reached the conclusion that these are independent objects comparable with the galactic system and affording the means of tracing the external universe to a depth of 10^7 to 10^8 light years. This is a remarkable prevision. The actual limits are of necessity vague, but Dr. Hubble doubts if any object at a distance beyond 10^9 light years has been recorded with the 100-inch.

But this conclusion, though it has been borne out in the main by subsequent research, was not universally accepted at the time. Thus a fundamental problem was still outstanding, and on its settlement Dr. Hubble has concentrated all his energy and all available methods and material. It is the comprehensive nature of the attack which commands our admiration. The status of the extra-galactic nebulæ has been firmly established, and if any uncertainty remains, that bears not on the nebulæ but on the model which is imposed naturally as the standard of comparison. For in some most important respects our knowledge of the galactic system is far less than our knowledge of the Andromeda nebula. We cannot see the galaxy from outside, and analogy can be a very untrustworthy guide. It is the old difficulty of seeing the wood for the trees.

Our Medallist's work on the extra-galactic nebulæ is so extensive that it is not easily summarized. Fortunately he has himself described it in his book, *The Realm of the Nebulæ*, and that work is now familiar to all those who are interested in this fascinating subject.

A suitable system of classification is a clear necessity, and it was one of Hubble's first cares to devise one for his own use. This has stood the test of time and is now generally adopted. Starting with the globular form, it runs through the sequence (*E*) of seven degrees of ellipticity. The series then divides into two branches (*S* and *SB*) of normal and barred spirals respectively, each with three subdivisions. There is also a small class (1 in 40) of irregular nebulæ, important because it contains the Magellanic Clouds. A relation between luminosity and diameter in the form $m + 5 \log d = C$ has been found to hold with an appropriate constant C for each subdivision. In the elliptical type the colour is uniform, but in the later, more developed spirals it becomes bluer, a fact associated with the occurrence of blue giants, whereas the elliptical nebulæ are unresolved. Hubble's classification is based on broad geometrical features, but signs are not wanting that it has some correspondence with a genuine physical sequence.

The problem to which Dr. Hubble has devoted himself has several sides, but one is fundamental, for on it everything depends. It is to establish a scale of distances. The first clue had been found when Ritchey in 1917 detected a nova in the spiral N.G.C. 6946. Following up this hint, Ritchey and Curtis found several novæ on their plates of M31, and Curtis came to the general conclusion already quoted. But there was a difficulty in the interpretation, even when the maximum could be established. The existence of two classes, now termed normal novæ and supernovæ, was already suspected, and identification with one or the other was disputed.

But another method attended by less ambiguity had been developed. In 1908 Miss Leavitt had noticed that in the lesser Magellanic Cloud the periods of the Cepheid variables are correlated with their luminosity, and further, in 1912 gave a definite relation. As these Magellanic stars are at a uniform distance this means that the absolute magnitudes of Cepheid variables are a function of their periods which would be definitely known if the distance of the Cloud were known. Alternatively, if the constant were determined from any group of similar variables at known distances, the distance of any Cepheid variable could be determined from its apparent magnitude and period. Hertzsprung determined the constant from a group of ordinary Cepheid variables, inferring their mean distance from the parallactic motions. Later the resulting relation was revised by Shapley, and the distance of both the Clouds is now placed in the neighbourhood of 90,000 light years. This must be taken to be beyond the boundary of the galactic system, and it rates the Magellanic Clouds as irregular nebulæ, though but for the test of distance they might both be taken for large irregular clusters.

The Clouds contain variables in abundance, but none had been detected in other nebulæ. In the meantime Hubble was greatly improving the

photographic resolving power of his plates, so that involved stars were clearly identified. Then in 1922 Duncan found three variables in M33, the faintest of which afterwards turned out to be of the Cepheid type. By 1926, 35 such stars and 2 novæ were known, and Hubble was able to fix the distance at 720,000 light years and to discuss the nebula in detail as a stellar system. But between 1923 and 1929, 40 Cepheid variables and 86 novæ had been found in M31 as the result of a deliberate campaign. Hubble's investigation led to the distance 680,000 light years. Even earlier Hubble had found 530,000 light years for the distance of N.G.C. 6822, and by the same methods 900,000 light years has been found for the distance of I.C. 1613. Thus by 1930 the work of Hubble had extended the scale of distances from the order 10^5 light years, represented by the Magellanic Clouds not far outside the galactic system, to the order 10^6 light years, which includes the few nebulæ which happen providentially to lie in our vicinity.

It is not possible to pause in order to notice the interesting details which emerge. The first steps towards a scale of distances must be based on the intrinsic properties of the stars resolved. In the end, when such stars fail as they must, the only guide is to be found in the type and total apparent luminosity of the nebula itself, and to use them it is necessary to know the absolute magnitude of each type and its dispersion. It becomes a question of photometry and statistics.

But Cepheid variables are not the brightest stars. So long as stars can be resolved at all it is assumed that the brightest star, actually the mean of the three or four brightest, tends to a standard absolute magnitude M_s. The assumption is really double, namely, that an upper limit exists as Sir A. Eddington has argued, and that it is in fact reached or closely approached among the very numerous stars in a nebula. From the few nearer nebulæ the mean value of M_s is found to be $-6{\cdot}1$. Further, the mean value of $M_s - M_{\text{neb}}$ is found to be $7{\cdot}84$, and hence $M_{\text{neb}} = -13{\cdot}94$. Both values are distributed more or less normally, and the dispersions, which are necessary for statistical applications, have been determined. Now in the nebulæ of the Virgo cluster the mean apparent magnitude of the brightest stars is estimated to be $20{\cdot}6$, whence $m - M_s = 26{\cdot}7$. The corresponding distance is about 7×10^6 light years, compared with Shapley's determination $1{\cdot}05 \times 10^7$ light years. Thus distances of the order of 10^7 light years have been reached. The direct application of this method cannot be pushed very much further with any existing telescope, since the photographic magnitude $21{\cdot}5$ is about the limit of visibility.

Another strand in Dr. Hubble's work must now be considered. The first radial velocities of nebulæ had been measured by Keeler in a classic research which owed nothing to large reflectors or help from photography. But these were galactic nebulæ with emission spectra, chosen precisely because their light is not frittered away in a continuous spectrum. The first radial velocity of an extra-galactic nebula was found in 1912, when Slipher measured the velocity of M31 and obtained a velocity of approach, -300 km./sec. In spite of a rapid spectrograph the work with a 24-inch

refractor was extremely laborious, but within the next thirteen years Slipher's patience had been rewarded with a list of 41 results, of which the largest was 1800 km./sec. and of which the majority were in the same sense of rapid recession.

It is needless to linger over the idle speculations to which the results gave rise. In 1929 Hubble had fairly accurate distances of 18 isolated nebulæ and the Virgo cluster. On combining these with the corresponding radial velocities he found a solar motion of 280 km./sec., normal peculiar motions of the order 160 km./sec., and in addition a radial recession proportional to the distance at the rate of 100 mi./sec. per million light years, or 520 km./sec. per million parsecs. The material on which Hubble based this investigation in 1929 may appear small. The material which Herschel used in order to obtain the first idea of the solar motion relative to the nearer stars was far smaller still.

The work which Slipher began and carried as far as his limited resources allowed was continued by Humason with the 100-inch. It may perhaps be remarked that Dr. Hubble has been as judicious in his choice of colleagues as in his choice of instruments. Humason obtained results for far fainter nebulæ extending to 42,000 km./sec. (or one-seventh of the velocity of light) for a cluster in Ursa Major. As the velocity-distance law was now fairly established, and peculiar motions are of no serious account in comparison with the recession velocity, the determination of distances is thus carried more than twice as far as 10^8 light years. The prediction of Curtis has been amply fulfilled, and in a remarkably short space of time.

When this stage had been reached much material had been gathered by converging lines of attack and a picture of the nebular universe had been drawn in broad and impressive lines. It was now possible to collate the facts and to verify that they were at least self-consistent. This condition they satisfy over a stupendous range. It has thus become possible to study the frequency law of the nebular luminosities and to extend the scale of distances in the statistical sense to the faintest nebulæ observable.

As a system the extra-galactic nebulæ resemble a stellar system and their distribution presents similar problems. The scale is vastly greater and the unit is a universe instead of a single star. There is a like tendency to form clusters, from a pair or a triple system through small groups to larger ones. An obvious difficulty arises from the obstruction presented by the galactic system, amounting to obliteration near the galactic plane. Dr. Hubble has come to the conclusion that the real distribution apart from local irregularities is essentially uniform in all directions and that proper allowance can be made for galactic absorption. He also considers that the distribution in depth, again apart from the effect of local clusters, is uniform to the limit of distance reached.

This brings us finally to what is likely to prove the most difficult aspect of the whole problem, and one which has engaged the attention of Dr. Hubble. It is obvious that the uniform distribution cannot continue indefinitely, at any rate in appearance, for in that case the whole surface of the sky would be of stellar brightness. It is the old remark made long ago about the stars.

Therefore either the universe of nebulæ thins out effectively at great distances, or the same effect is brought about by the dissipation or absorption of the light. Dr. Hubble has carried out surveys of the nebulæ to definite limiting magnitudes, and has found a certain falling off in the numbers. But this he attributes to the diminution of apparent magnitudes at great distances. Some disturbing effects suggest themselves. When the velocities are a sensible fraction of the velocity of light, the whole spectrum is shifted redward and the photographic magnitude is naturally changed. Also when the frequencies of the radiation are diminished from any cause, quantum theory requires a corresponding decrease in the intensity.

But this is not all. We have spoken of the velocities of recession, but the objective fact is the red shift or the lengthening of the wave-lengths, which implies radial velocity on the Doppler interpretation. This interpretation suits the relativists, who have adopted the whole effect as a measure of the rate of expansion of the universe. But without disputing the theory of the expanding universe, there is nothing to prove that the rate of expansion coincides with the observed rate of 530 km./sec. per million parsecs, and perhaps some difficulties which suggest a doubt. On the other hand, the observed effect could be attributed to a simple property of light by which the wave-length of radiation is lengthened in transmission. There is nothing to corroborate such a possibility, but, on the other hand, it is clearly beyond the range of physical experiment to disprove it. Dr. Hubble has kept an open mind on the subject and in conjunction with Professor Tolman has devised tests in order to discriminate between the kinetic and any alternative explanation of the facts. They depend on the effective absorption of the light of the nebulæ in space, and involve the distribution as indicated by the surveys to different magnitudes. The results tend rather against the theory of expansion than in its favour, but they are far from conclusive. In any case the relativists are tenacious and can be trusted to hold their ground. It is a measure of Dr. Hubble's success in the development of the whole subject that he is now face to face with a problem of such magnitude and difficulty.

This is but a bald account of what our Medallist has done, and it omits all those details which go to make up a graphic and, we believe, lifelike picture, though it cannot be a simultaneous picture, of the expanded universe as he has drawn it. In particular it leaves out all reference to the masses of the various systems which have led him to place the mean density of nebular material between 10^{-28} and 10^{-30} gr./cm.^{3}. These are wide limits, but clear and unambiguous evidence is hard to obtain. By giant strides Dr. Hubble has marched boldly forward to distances from 10^5 to 10^6, 10^7, 10^8 and even 10^9 light years away. Like all who have used the world's greatest telescopes in this unending adventure, he has voyaged through strange seas of space alone. He has followed worthily in the footsteps of our first President, Sir William Herschel.

If we look back over the last fifty years ending to-day, we find that in two of these years the medal was not awarded. Of the 48 medals which have been awarded, 18 have been given to British subjects, 16 to citizens

of the United States and 14 to other nationals. But America has a claim to have the name of Ernest Brown transferred to her list. If it be granted, it can be said that over this half-century the balance between the two branches of the English-speaking race has been held exactly even. In the last ten years this is the fifth medal to go to America.

Astronomy knows no distinction of race or nationality. In these realms of intellectual conquest which our Medallist has done so much to extend these words have no meaning. There is only rivalry in good work and friendly co-operation. But we do not forget that Dr. Hubble has known us as a Rhodes Scholar at Oxford, and our tribute has something more personal on that account.

Mr. Schoenfeld, on behalf of the Royal Astronomical Society I thank you for your presence at our meeting this afternoon as the representative of that great country which has cultivated astronomy with ever-increasing liberality and success. This medal represents the highest mark of our appreciation for individual work contributing to the progress of the science to which we are devoted. I now place it in your hands and beg that you will be so good as to transmit it to your distinguished countryman, Dr. Edwin Hubble, of the Mount Wilson Observatory. With it go our heartiest congratulations and our fervent hope that a long and fruitful life still lies before him.

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